ELECTRICITY

IN

FACTORIES AND WORKSHOPS

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Its Cost and Convenience

A HANDY BOOK FOR

POWER PRODUCERS AND POWER USERS

BY

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WITH NUMEROUS ILLUSTRATIONS.

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PREFACE.

THIS book is an attempt to show what a convenience the electric motor, in its various forms, has become to the modern manufacturer.

It also deals with the conditions which determine the cost of electric driving, and compares this with other methods of producing and utilising power.

The figures used in the various estimates of working cost are those which may be expected under ordinary working conditions, and they consequently differ from those obtained under test conditions, or in cases where special care is bestowed upon the machinery.

An allowance at the rate of 10 per cent. per annum has been taken into account in all estimates and comparisons, to cover interest and depreciation charges. I am aware that strict accountancy practice demands a higher rate, but I have chosen this figure as a fair average of those usually taken into account when making cost comparisons of this description. As all figures are given in detail they can easily be modified to suit any particular special conditions.

The applications referred to in Section III. are in no way exhaustive, but they show how easily the electric motor adapts itself to practically any requirement.

The generation and distribution of electrical energy from public supply stations is not dealt with in this

book, or the employment of the electric current for heating and electro-chemical purposes.

I wish to thank my friend, Mr Andrew Stewart, A.M.I.E.E., for the figures comparing the cost of using electric and hydraulic portable tools, and for the assistance he has given me in correcting proofs.

I am also indebted to the following for the loan of electros and for information regarding their work:—

Messrs the Adams Manufacturing Co. Ltd., Alfred Herbert Ltd., the British Westinghouse Electric and Manufacturing Co. Ltd., the Consolidated Pneumatic Tool Co. Ltd., the Dowson Economic Gas and Power Co. Ltd., the Electric and Ordnance Accessories Co. Ltd., Electric Construction Co. Ltd., Electromotors Ltd., the Electric Controller and Supply Co. Ltd., Kohler Bros., Laurence, Scott, & Co. Ltd., Mather & Platt Ltd., the Sandycroft Foundry Co. Ltd., Siemens Bros. Dynamo Works Ltd., A. Reyrolle & Co. Ltd., and Mr W. B. Woodhouse, A.M.I.E.E.

A. P. H.

"Coniston,"
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THE name "electric motor" is given to any machine which will convert electrical into mechanical energy. It is possible to effect this conversion in different ways, and the term includes machines which at first sight appear to have little in common. They are, however, easily separated into classes, depending, first, on the system of supply of electrical energy on which they are intended to work, and secondly, on the particular class of work they have to do.

The systems of supply divide themselves generally into two, namely—

(*a.*) Direct current,
(*b.*) Alternating current;

and the character of the work they are required to perform, also into two—

(*a.*) Those for which constant speed under all conditions is essential, and
(*b.*) Those in which the speed of the motor can be easily varied to suit the work which is being done.

It will be best to follow this general classification in describing the various types of motors, leaving to later

chapters, the task of proving how completely they fulfil practically every requirement of industrial life.

In direct current circuits the electric energy always flows along the conductor in the same direction. Whenever a steady difference of electrical pressure is maintained between two points in a closed electrical circuit, a direct current flows along the conductor.

Direct currents are obtained from primary and secondary batteries, and are subject without reservation to the law first stated by Dr George Ohm in 1827 and since known as Ohm's Law, which states that—

"The rate of flow of current in a closed electric circuit varies directly as the difference of electrical pressure between any two points, and inversely as the electrical resistance between the same points."

Expressing this in terms of the usual units of electrical pressure, rate of flow of current, and resistance, this reads—

"The amperes flowing in an electrical circuit vary directly as the volts between any two points of the circuit and inversely as the resistance in ohms of the circuit between the same points," or—

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}}.$$

$$\text{Ohms} = \frac{\text{volts}}{\text{amperes}}.$$

$$\text{Volts} = \text{amperes} \times \text{ohms}.$$

The volt is the name of the unit of electrical pressure. It has a definite legal definition, but in practice may be taken as half the pressure at the terminals of an accumulator during the period of discharge.

The ampere is the name of the unit of rate of flow of an electrical current. It is that rate of flow of current which is maintained in a circuit having a resistance of one ohm by an electrical pressure of one volt. Its legal definition is the rate of flow of current of unvarying strength which will

deposit 0·001118 gramme or 0·01725 grain of silver in one second from a solution of nitrate of silver.

The ohm is the name given to the unit of electrical resistance, and may be said to be that resistance which causes a current of one ampere to flow when the electrical pressure is one volt. Legally it is the resistance to the flow of an unvarying current offered by a column of pure mercury at the temperature of melting ice, the column of mercury having a constant sectional area, a length of 106·3 centimetres or 270 inches and a mass of 14·4521 grammes or 223 grains. This law, and these definitions, are mentioned here to show the interdependence of pressure, resistance, and rate of flow of current upon each other.

The electric motor, like the dynamo, is the child of the great scientist, Michael Faraday, whose work is valued as highly as his memory is revered. In 1821 he discovered that when a wire carrying an electric current was pivoted at one end, and left free to revolve at the other over the pole of a magnet, the free end of the wire dipping into mercury, the wire moved round the magnet pole so long as the flow of the current was maintained. In the following year he improved his apparatus, and produced the first device which continuously converted electrical into mechanical energy. Great interest was felt in this discovery, and within a few years a number of electric motors, or, as they were termed, electro-magnetic engines, were made, some of them of large size. In fact, within twenty years, both Davenport in the United States, and Davidson in Scotland had succeeded in driving tramcars by means of these engines.

In 1831 Faraday made that historic discovery of magnetic induction, which made possible the conversion of mechanical into electrical energy, and so paved the way for the modern dynamo. In a paper read before the Royal Society, he showed that if a magnet is moved towards a coil of wire, the ends of which are connected together, a current of electricity is induced in the coil, the current flowing in one

direction as the magnet is moved towards the coil, and in the opposite direction as it is moved away from the coil. He also pointed out that the strength of the induced current varied with the strength of the magnet, and the rate at which the magnet was moved to or from the coil. The possibility of transforming mechanical into electrical energy having been proved, it was not long before a number of electrical generators were devised, the early machines giving alternating currents.

It was next found that the addition of a commutator to the generator caused the currents to flow in the same direction in the external circuit. The labours of Gramme, Siemens, and other workers in the early seventies transformed the dynamo from a philosophical toy into a practical machine for the production of electric energy, and thus commenced the era of commercial electrical engineering work.

Meantime, little progress had been made with the motor or electro-magnetic engine. The early machines were supplied with current generated from primary batteries, and were very inefficient in themselves, as well as expensive to maintain.

It was generally thought that a motor could not have a higher efficiency than 50 per cent., and till the late seventies practically no progress was made. At that time Siemens made a careful study of the subject, and showed that the dynamo was a reversible machine, that is, that when mechanically driven it produced electric currents, and when supplied with electric currents it worked as a motor. He also proved that the prevailing idea of motor efficiency was based on the error that a motor worked under the most economical conditions when it worked at the maximum rate. He pointed out, that the efficiency of a motor depended upon the relation of its speed or counter electrical pressure to that of the dynamo driving it, and that the nearer these two speeds or electrical

pressures approached each other, the higher the efficiency of the motor, though he clearly saw that under these conditions the motor was not working at its maximum rate.

Progress after this was rapid. It was felt that the electric motor was likely to prove a practical tool, and considerable attention was paid to its design. For some years the aim of most workers was to make the motor as light as possible, and, to gain this end, the motor armatures were made very large in comparison with the field magnets. The result was that the machines sparked badly when the load was varied, and the speed varied with every change in the load. It is curious now to read of the ingenious suggestions which were made of methods of governing the motor speed by centrifugal and other mechanical means.

In 1886 Mordey showed that a shunt wound dynamo, with an armature small in comparison with the field magnets, ran as a motor at practically constant speed with widely varying loads without undue sparking at the brushes. He proved that in motors, as in dynamos, the best way to reduce sparking was to use very powerful field magnets and relatively small and weak armatures. In this way the cross-magnetising action of the armature was minimised, the speed under varying load was kept constant, and sparking was considerably reduced. Since that time, progress has been largely in mechanical details, the design has been improved, the best class of materials to use have been gradually settled upon, and the methods of manufacture have been standardised.

The different parts of a modern direct current motor are shown in Fig. 1, which represents Messrs Laurence, Scott, & Co.'s standard design. The general arrangement is such that the casing of the machine forms the supports for the bearing shells.

The frame and field poles with coils are shown in the background. The frame is of cast iron or steel, and serves

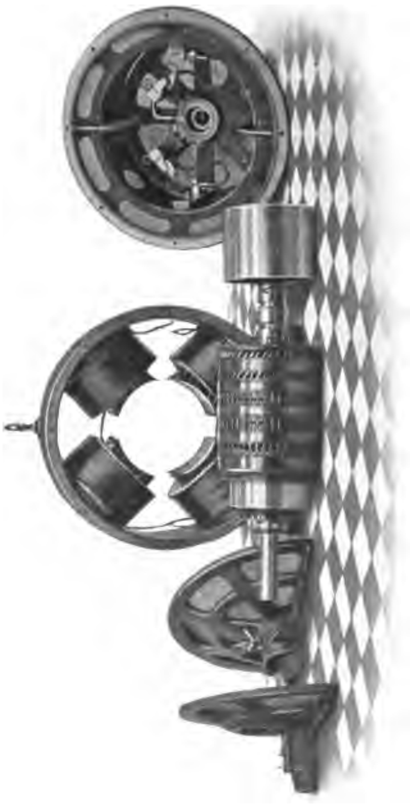

Fig. 1.—Separate Parts of a Direct Current Motor.

the double purpose of an outside casing and a yoke for the field magnet poles. Some makers rib the outside of the frame to give a larger radiating surface, and so keep the motor cooler when working for long periods. The field poles are sometimes of cast steel, but in the best class of machines they consist of steel stampings. When the cores are solid, the pole tips are usually laminated, as this reduces the eddy current losses. The magnetising coils are wound on insulated formers, and are slipped over the cores when the motor is assembled. They are secured in position by wedges. These coils consist either of a few turns of thick wire or many turns of fine wire, according as the motor is series or shunt wound.

The armature is shown in the front of the illustration. The core consists of a number of thin steel stampings pressed together and closely fitting the axle. The stampings are insulated from each other by coating them with a thin layer of special insulating varnish. Till recently the coils were often wound on the surface of the core, but as there is a strong pull between the magnet poles and the armature conductors it often happened that in times of emergency, if the motor were suddenly overloaded, the coils would be dragged out of place and the armature damaged. It is now usual to stamp slots in the armature core plates, so that when they are fitted in place they form troughs for the armature coils. In this way a positive drive is obtained, and all risk of stripping the armature is obviated.

Practically all motor armatures are of the shape illustrated, or "drum wound." The method of winding the coils and connecting them to the commutator can best be explained by reference to diagrams, and Figs. 2 and 3 show two usual methods of arranging the coils in a four pole machine, Fig. 2 being termed "lap winding" and Fig. 3 wave winding. Taking the "lap winding" diagram, Fig. 2, the figures on the circumference represent slots in the core, and the lettered portions of the smaller circle segment of the commutator

and the crosses in the centre represent currents flowing into the armature, and dots in the circles currents flowing out of the armature.

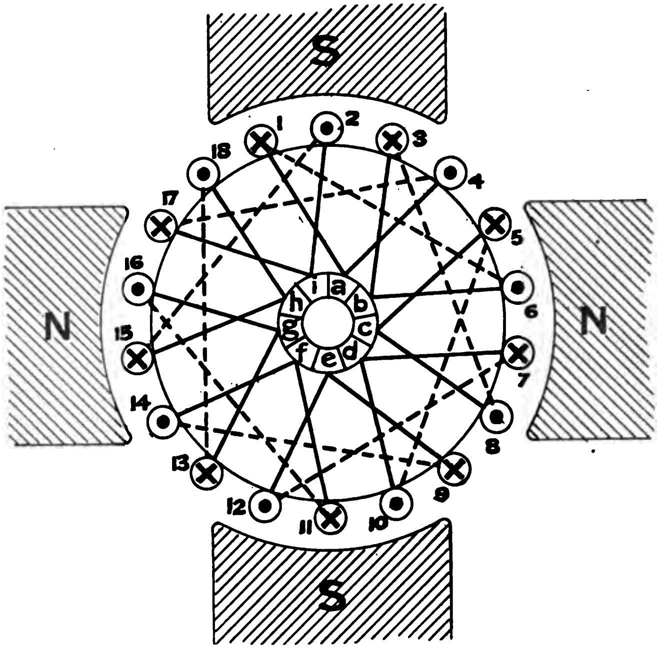

Fig. 2.—Diagram showing Lap Winding of Direct Current Motor Armature.

The circuit through the armature runs thus :—

a –	1 in	6 out	– *b*	*f* –	11 in	16 out	– *g*
b –	3 „	8 „	– *c*	*g* –	13 „	18 „	– *h*
c –	5 „	10 „	– *d*	*h* –	15 „	2 „	– *i*
d –	7 „	12 „	– *e*	*i* –	17 „	4 „	– *a*
e –	9 „	14 „	– *f*				

The full lines represent connections in front, and the dotted ones those at the back of the armature.

The wave method of arranging the coils is shown on Fig. 3. In this the circuit starting from *a* would be :—

a –	6 in	11 out	– *f*		*h* –	2 in	7 out	– *d*
f –	16 ,,	3 ,,	– *b*		*d* –	12 ,,	17 ,,	– *i*
b –	8 ,,	13 ,,	– *g*		*i* –	4 ,,	9 ,,	– *e*
g –	18 ,,	5 ,,	– *c*		*e* –	14 ,,	1 ,,	– *a*
c –	10 ,,	15 ,,	– *h*					

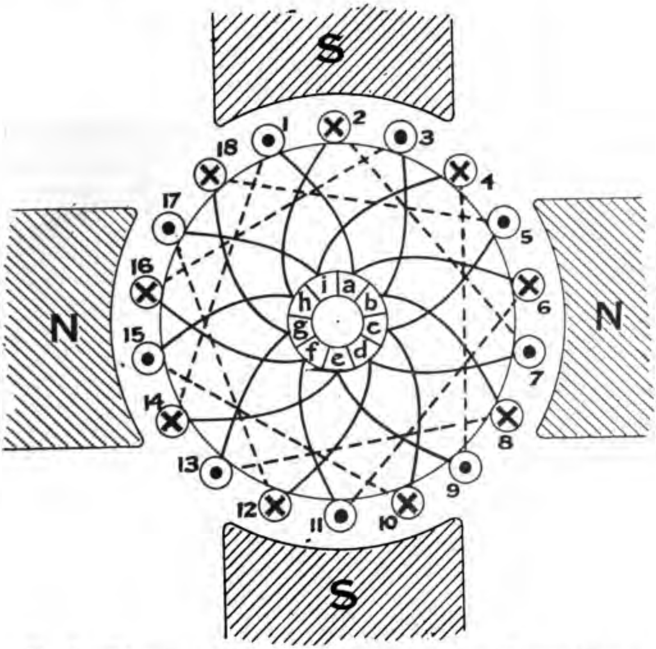

Fig. 3.—Diagram showing Wave Winding of Direct Current Motor Armature.

There is no difference in the action of the two forms of winding—it is merely a matter of convenience and of facility in manufacture. The wave form of winding is perhaps the

most popular as it permits of easier replacement of damaged coils.

The commutator is one of the most important parts of the armature. It is shown to the left of the core in Fig. 1, and consists of a number of wedge-shaped pieces of specially prepared copper, shaped together to form a cylinder. Fig.

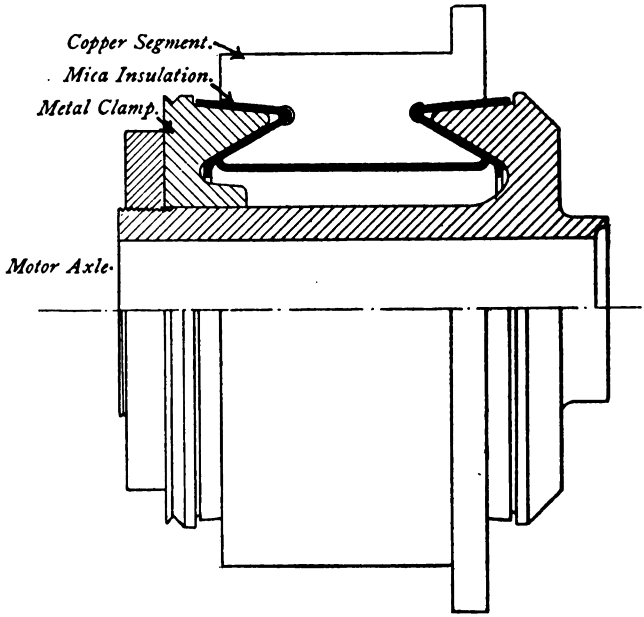

Fig. 4.—Method of Fixing Commutator Bar.

4 shows a method used by Messrs Electromotors Ltd. for fixing these bars to the axle, and at the same time insulating them from it. Mica is the usual insulating material. After the commutator parts are secured in position, the surface is carefully machined. In well-designed motors there are a large number of commutator bars, and the only electrical

connection between successive bars is through the respective coils as shown in the winding diagrams.

The sides of the motor support the bearings, which are usually cast-iron shells lined with white metal, and need to be of ample size and length. The method of lubrication usually adopted is that of a loose ring dipping into an oil well, as shown on Fig. 5, which shows Messrs Electromotors' standard pattern. Although it seems a very simple thing, the

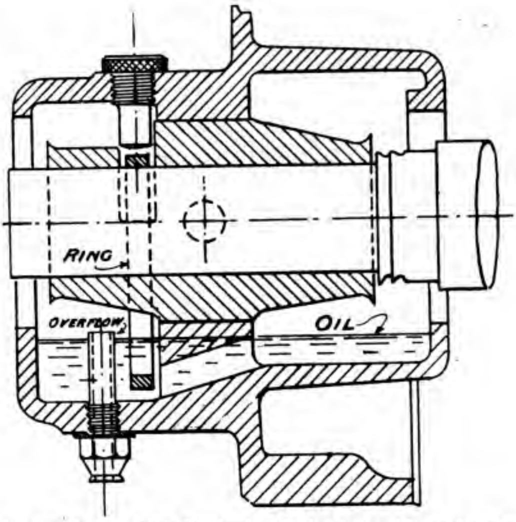

Fig. 5.—Loose Ring Method of Lubricating Motor Bearing.

application, now many years ago, of the loose ring or chain methods of lubricating motors and dynamos had much to do with their practical success. Many other methods were tried, but all proved more or less failures. As soon as these forms were tried, troubles from imperfect lubrication practically ceased.

The only remaining essentials are the brush holder and brushes. In a four pole machine the brushes which serve

Fig. 6.—Open Type Direct Current Motor.

Fig. 7.—Enclosed Type Direct Current Motor.

the purpose of collecting the current from the armature are placed 90° apart. They may be made of copper or carbon, and are held in position by the brush holders, which are fixed to the framework of the motor. The brushes need to be gently pressed against the surface of the commutator, and each maker has his own special arrangement of springs and spring catch. Many of these are very simple and thoroughly effective, and present a great contrast to the flimsy complicated forms used ten or fifteen years ago.

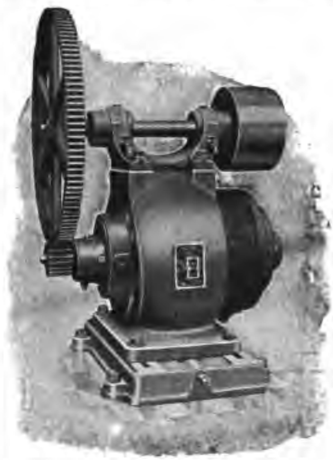

Fig. 8.—Direct Current Motor, with Back Spur Gearing.

Several patterns of direct current motors, as made by Messrs Electromotors Ltd., are shown in Figs. 6, 7, and 8.

The characteristics of a motor are largely determined by whether the field coils are series, shunt, or compound wound. The differences between the three windings are diagrammatically shown in Figs. 9, 10, and 11.

In Fig. 9 the whole of the current flows first round the field magnet coils and then through the armature coils. This is known as a series wound motor winding.

Fig. 10 illustrates a shunt motor winding. Here the current supplied to the motor divides at the motor terminals into two parts, one portion flowing through the armature and the other portion through the field magnet coils.

The winding of a compound wound motor is shown in Fig. 11. Here the current divides at the motor terminals

as in a shunt wound machine, one portion flowing through the field coils, but the other part, before flowing through

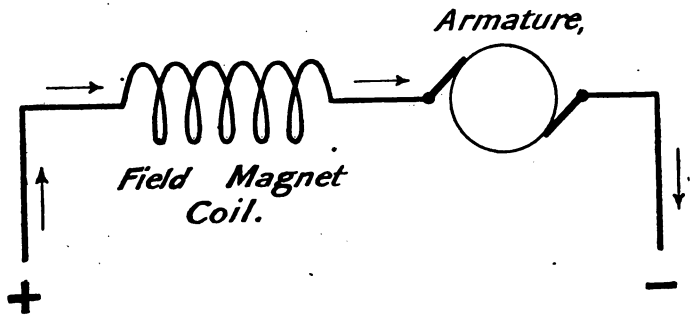

Fig. 9.—Arrangement of Winding for Series Wound Motor.

the armature, flows round a few turns of extra field magnet coils. This winding may be arranged either to help or

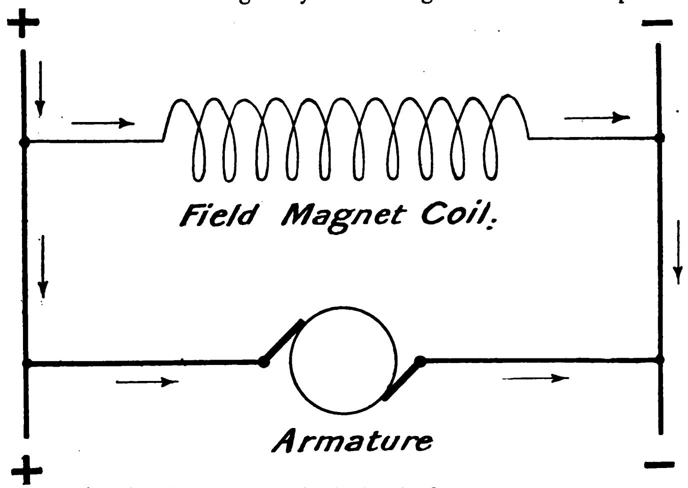

Fig. 10.—Arrangement of Winding for Shunt Wound Motor.

oppose the shunt coils, each arrangement having its special uses.

In the above diagrams the current is supposed to flow from the + or positive terminal of the motor to the – or negative one.

Speaking generally, when motors are required to run at constant speed under varying conditions of load, shunt wound machines are used, series wound motors being preferred when large starting effort combined with wide variation of motor speed is necessary.

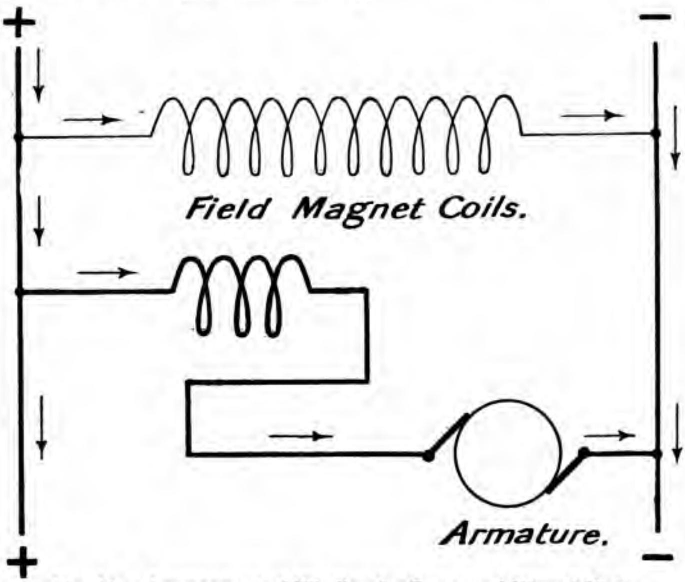

Fig. 11.—Arrangement of Winding for Compound Wound Motor.

With series motors the whole current flows through both field coils and armature. The wires used must therefore be of large size so that they are not overheated when the motor works either at full load for a long period, or is overloaded for a short period. The number of field magnet turns may be few, since the magnetic effect depends upon the ampere turns, that is the product of the number of amperes flowing along the wire into the number of turns.

The general relationship between ampere turns or magnetising force and magnetic effect for an average sample of steel is shown in Fig. 12. It will be noticed that at first the increase in magnetic strength is directly proportional to the increase in magnetising force, but that as the steel becomes what is termed saturated, the rate of increase of magnetic strength, with increase of magnetising force, becomes less and less until at length increase of magnetising force produces very little effect on the magnetic strength. The exact effect which a given number of ampere

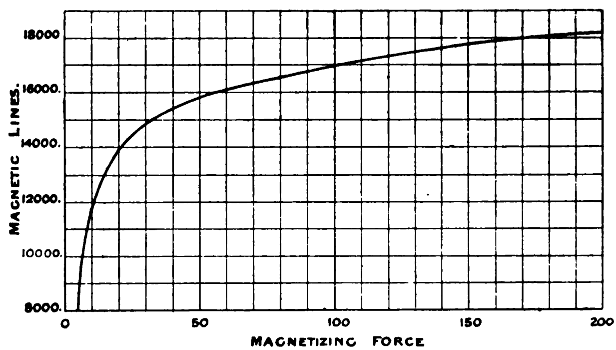

Fig. 12.—Relation between Magnetising Force and number of Lines of Magnetic Strength.

turns or magnetising force will have upon a sample of iron or steel depends upon its composition and physical condition, and great care has to be exercised in choosing suitable qualities of steel for both magnet cores and armature stampings, and testing carefully to see that the materials actually used fulfil the required conditions. There is very little permanent magnetism in motor field poles, the magnetic strength depending upon the effective ampere turns at any given moment.

The mechanical work done by a motor depends upon the speed and the turning moment or torque as it is usually termed, and, speaking generally, the torque depends upon the magnetic strength and the armature current. Expressed in suitable units, the work done may be said to be the product of the speed and the torque. There are definite relationships between the character of the electrical supply, the design, and what is termed the speed characteristic of the motor which are fully considered in larger works on this subject.

When a series wound motor is switched on, the whole of the current flows through both field coils and armature. The effect on the field will be to bring the magnetic strength to practically its full amount, and the "torque" or starting effort—which may be considered as the product of magnet strength and armature current—will be a maximum for that particular value of current. With its high starting torque the series motor is therefore excellent for crane, tramcar, or similar work. As the series wound motor working on a constant pressure circuit increases its speed—unless outside resistances are varied—it automatically reduces the current flowing through it. This is due to the opposing electrical pressure set up by the rotation of the armature conductors in the motor magnetic field. This opposing pressure must be deducted from the total electrical pressure of the circuit to obtain the effective pressure available at any moment to force a current through the motor.

This opposing or counter electrical pressure is that which, if working as a dynamo, the motor would generate at that particular speed and strength of magnetic field. The increase of motor speed and the consequent reduction in the strength of the current affects the torque of a series wound motor in two ways, for not only is the current itself reduced, but the ampere turns, and consequently the magnet strength, is reduced also. The torque or the product of these values varies, therefore, to a greater extent than the speed,

with the result that, unless other methods of control are used, the speed under these conditions varies with the work. The extent of this variation depends to some degree upon the electrical resistance of the motor, and is smallest in motors having very low resistance field coils and armature conductors.

In a shunt wound motor the conditions are somewhat different. Here, as shown on Fig. 10, the current divides at the terminals of the motor. The field coils consist of many turns of comparatively fine wire, and consequently only a small current flows through this part of the circuit. Since the magnet strength is dependent upon the number of ampere turns it is immaterial whether this is obtained with large current and few turns of wire, or by small current and many turns. In the series motor the ampere turns of the field coils vary directly with the current flowing through the armature, in the shunt wound motor the field coil circuit is independent of the armature circuit, and therefore independent of the work which is being done. The magnetic strength of the field is therefore nearly constant the whole time the motor is at work, the only variation being due to the cross-magnetising effect of the armature current.

On starting a shunt wound motor the torque depends upon the product of the ordinary strength of the motor field and the current flowing through the armature, and though this is practically in every case sufficient to start the motor under full load, it is less than that obtained with a series wound motor of similar size on starting. As the speed of the motor increases, the armature current is reduced due to the lowering of the effective electrical pressure by reason of the higher counter electrical pressure caused by the rotation of the motor armature in the magnetic field. The torque, however, is affected to a far less extent than in the series wound motor, since one of the factors on which it depends, namely, the strength of

the magnetic field, is practically constant. The torque, therefore, varies inversely as the speed; increase the speed, the armature current, and consequently the torque, is decreased; decrease the speed by loading up the motor, the current and the torque are increased too. By keeping the armature resistance low, it is possible to make the armature current so sensitive to changes in the motor speed that the torque will practically vary as the load, and the speed will be kept constant within about 3 per cent., whatever the variations in load between no load and normal full load. A shunt wound motor may therefore be used when nearly constant speed is required with varying load, and it is not necessary to start the motor against excessive overloads.

If instead of keeping the strength of the shunt motor field constant, it is weakened as the load is increased by inserting resistances in the field magnet circuit, the speed of the motor may be varied within wide limits. The effect on a constant pressure circuit of weakening the strength of the motor field is to keep down the counter electrical pressure, and consequently to increase the armature current as well as to increase the speed. Whether the torque is altered depends on the relative values of the armature current and strength of motor field. A weak field, however, increases the tendency of the motor to spark at the commutator, especially when there is a large armature current.

Careful design and the choice and use of the best steel in the field poles and armature core have made it possible in some motors to obtain a range of speed regulation of 4 to 1 without undue sparking with an ordinary shunt wound motor by altering the strength of the field. It must, however, be remembered that the size of the motor is determined by the amount of work it can do at the lowest speed, and that if, for instance, a lathe or machine tool needs to be worked at any speed between 250 and 750 revolutions per minute, the motor must be large enough to do the full work at the lowest speed, and will be of three

times the capacity than if it were only required to give full load at the higher speed.

During the past few years it has been found to be possible to reduce the sparking of dynamos and motors worked at varying loads in several ways, the most popular of which is to provide small magnet poles in addition to the ordinary poles, and to place these between the principal poles of the machine. These extra poles are energised by coils placed in series with the armature circuit, and their use is to neutralise the cross-magnetising effect of the armature current, and by maintaining the effective strength of the principal poles to reduce the sparking at the commutator. The effect of these extra poles is proportional to the need, being a maximum, when the armature current and consequently its cross-magnetising effect on the field strength are greatest. "Interpole" motors, as such motors are termed, are naturally more expensive to manufacture, but the use of these subsidiary poles enables a speed regulation of 6 to 1 to be obtained, and increases the value of the motor for many purposes.

The third class of motors have their field circuits compound wound. The arrangement is shown on Fig. 11. There is not only the independent shunt circuit, but a few coils in addition, in series with the armature. In the illustration the series coils are shown so connected that they strengthen the magnet field. Such an arrangement improves the starting torque of the motor, but decreases the constancy of the speed with varying load. Another plan is to arrange the series winding so that it opposes the shunt winding, and weakens the field. This method of connection increases the self-regulating power of the motor under varying loads, but makes its starting, uncertain and difficult, since it may happen that the rush of current in the series coils may not only weaken but altogether overcome the effect of the shunt coils. The magnet poles will then be magnetised in the wrong direction, the motor

will start running backwards, and there will be excessive sparking at the commutator. This may be avoided by arranging switches, so that on starting, the series coils help the shunt coils, and after the motor has started altering the switch so that the direction of flow of current is reversed, and the series coils weaken instead of strengthen the field. This arrangement is effective, but is not often used, since the act of reversing causes a sudden variation in the speed.

If motors are to run without trouble, it is important that care should be taken in choosing and fitting the brushes. In the early days copper gauze brushes placed at an angle to the commutator were almost universally used. These acted well, so long as the motor ran in the same direction, but were often ruined if the direction of rotation were accidentally reversed. It was not therefore practicable to use them with tramway or crane motors where the direction of rotation is constantly reversed. Carbon brushes were tried, and after many experiments and failures proved successful, and are now used very largely for both dynamos and motors.

The brushes now generally used, consist of small blocks of specially prepared graphite which press at right angles on the motor commutator. It is therefore not affected by alterations in the direction of rotation of the motor. It is necessary to allow a much larger area of contact surface with the commutator with carbon brushes since carbon is not so good a conductor of electricity, but when the right quality of carbon has been selected, the attention required is small, and the result very satisfactory.

There are many purposes for which it is more convenient that the motor should be arranged to run with the armature axle vertical instead of horizontal. A number of makers have devoted much attention to this design, with the result that vertical motors are now made to run as reliably as horizontal. The great point to consider is the arrangement of the main bearing as this has to carry the whole weight of the armature.

CHAPTER II.

THE ALTERNATING CURRENT MOTOR.

Alternating Currents—Periodicity—Power Factor—Single and Polyphase Currents—Methods of Connection for Two and Three Phase Circuits — Types of Alternating Current Motors — Synchronous Motors —Induction Motors—Relation between Speed and Number of Poles—"Slip"--Starting Properties—"Squirrel Cage" and Slip Ring Motors—Effect of Overload on Induction Motors—Variable Speed Induction Motors—Commutator Type Motors.

IN some districts the public supply of electricity is by means of alternating currents. These differ from direct currents in that the direction of the electrical pressure and of the flow of current is constantly altering. In practice, where the currents are generated either by magnet poles rotating in front of fixed coils of conductors, or by the conductor coils revolving in front of fixed magnet poles, these changes are of a periodic character. In their simplest form they follow a cycle resembling a sine curve, but usually the wave form is of a much more complex character.

Thus if in Fig. 13, divisions on the line AC are taken to represent time, and vertical distances electrical pressure, the distance AC being the time taken for a complete cycle of changes, the following effects will be found:—During the first quarter period the pressure rises from zero to a maximum, during the next similar period it falls to zero at B, then it changes in direction, and during the third quarter period it rises to a maximum equal to, but opposite in direction to the first period, while during the last quarter

period it rises to zero ready to recommence the same cycle of changes.

As applied to industrial purposes in this country alternating currents are usually employed of such a character that the number of complete cycles of change, that is the rise and fall of pressure in one direction, and the rise and fall in the other represented by the full distance AC on Fig. 13, varies between 25 and 60 in each second. For some purposes the lower number is more suitable, but the general standard for a mixed supply of power and light is 50. This is termed the periodicity or frequency of the circuit, and is denoted by the sign ~. The figure of 50 ~ is a compromise between

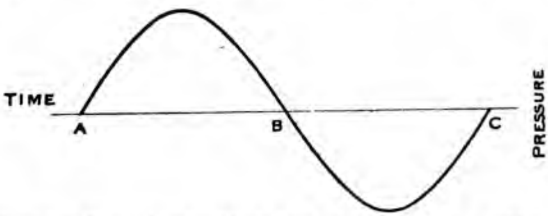

Fig. 13.—Curve showing Variation in Pressure in Single-Phase Circuit.

opposing requirements. With much lower periodicities thoroughly satisfactory lighting is not obtained, while for motors a low periodicity has certain advantages.

If the electrical circuit is "non-inductive," the changes in current strength follow exactly the changes in electrical pressure, but if the circuit includes coils of wire, either with or without iron cores, the flow of current is retarded, and although the changes in current strength will be the same in character as the changes in pressure, there will be a slight interval of time between the two, the extent of this interval depending on the character of the load in the external circuit. The effect at any given instant is that the current differs from what it should be according to

Ohm's law, being less while the pressure curve is advancing from zero to a maximum, and greater while the pressure curve is falling to zero. The average effect is the same as if an extra resistance had been added to the real resistance of the circuit, this added resistance depending on the character of the load. This apparent resistance is technically termed the "impedance" of the circuit, and its existence is the cause of many of the differences between alternating and direct current effects.

This alteration in the relationship of the rate of flow of current to the electrical pressure means also that at any given instant the actual work done in a circuit—which depends partly upon the rate of flow of current in that circuit—is less than it should be if calculated, as with direct currents, from the pressure and rate of flow of current. The ratio of the real work being done at any moment, to the work—which if there were no impedance might be done—is called the "power factor" of the circuit, and this varies with the character of the load. If an alternator is supplying incandescent lamps, where there is practically no impedance, the power factor is 1, while if it is supplying energy for a number of motors the power factor will be ·80 or ·85, which means that to do the same amount of real work the alternator must be proportionately larger; in other words, the full load current from an alternator will do less work when running motors than when supplying incandescent lamps this diminution of useful effect being proportional to the fall in the power factor. It follows, that as the currents to do definite amounts of work in a circuit are greater when the power factor is low, that the cables must be larger or the loss in distribution will be proportionately greater too.

An alternating current of the character shown on Fig. 13 is termed single phase. It is, however, possible, and in many cases convenient, so to arrange the circuits in an alternator, that what are termed polyphase currents are obtained. These are usually two or three phase, though

there is no theoretical limit either to the number of the phases or the shape of the different waves.

In a two-phase current, the simplest form of which is shown on Fig. 14, there are two waves of electrical pressure in each cycle, one of which is a quarter of a cycle or period

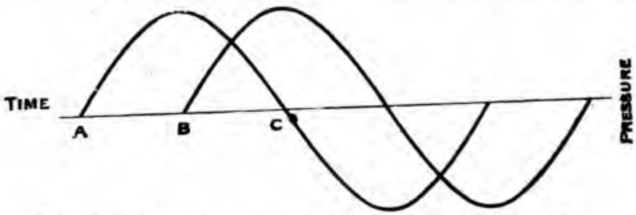

Fig. 14.—Curves showing Variation in Pressures in Two-Phase Circuits.

(AB) behind the other. Thus one is a maximum when the other is a minimum.

Similarly it is possible to have three waves of electrical pressure and current as shown on Fig. 15, where successive waves of current are one-sixth of a cycle (AB) behind the other.

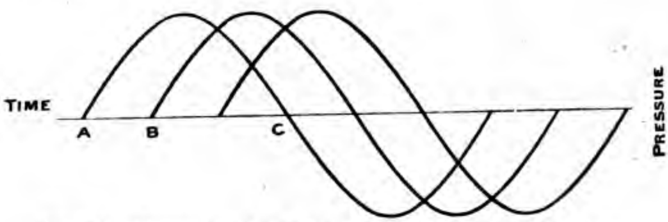

Fig. 15.—Curves showing Variations in Pressures in Three-Phase Circuits.

It is easy to obtain these two and three phase currents in practice, as it only means arranging the armature windings so that the coils belonging to the separate phases are spaced the right distance from each other. The effective output of a given alternator is greater when wound for two phase than

one phase, and when wound for three phase than for either two or one phase.

Two and three phase currents have some important advantages over single-phase currents for motor work, and when energy is distributed for power as well as lighting work, two or three phase currents are generally employed.

It is usual, but not necessary, to have four wires when two-phase currents are used, as shown on Fig. 16, the two armature separate circuits being connected to the two line circuits. These act precisely as if they were separate single-

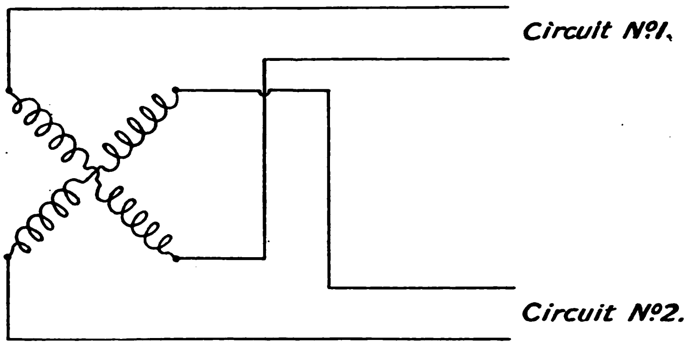

Fig. 16.—Method of Connecting up Two-Phase Wound Armature to External Circuits.

phase circuits so far as the outside load is concerned, and may be each used for the supply of energy to lamps or single-phase motors. If, however, the best effects are wanted for motor work, two-phase motors are used, and the four wires connected to the respective motor terminals. Three wires may be used if desired, one wire being common to both circuits.

With three-phase circuits three wires are all that is necessary, though four wires are often used. In Fig. 17 what is termed the "star" connection with three outside wires is illustrated. By making one conductor common to the two circuits, it is possible to dispense with one wire and

use only three conductors. The three phases radiate from a common centre, and the three conductors are connected to their terminals. Here the three circuits are AB, AC, and BC,

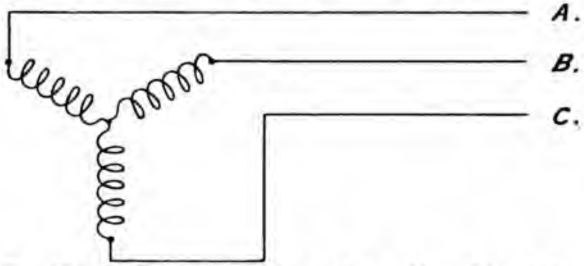

Fig. 17.—Method of Connecting up Three-Phase Wound Star Armature to Three-Wire External Circuit.

and it will be noted that the same conductors are used for two of the phases, the current in one phase being 60°, or one-sixth of a cycle in advance of the current in the other.

In Fig. 18 the use of four wires with the star connection

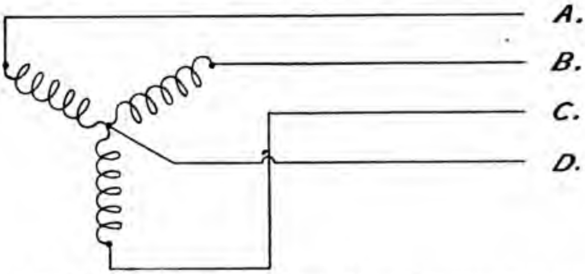

Fig. 18.—Method of Connecting up Three-Phase Star Wound Armature to Four-Wire External Circuit.

is shown. The fourth wire is connected to the neutral point of the armature, and the separate circuits are usually taken between AD, BD, and CD, D being a common wire to all three phases.

There is another way of connecting the conductors in a

three-phase system, namely, as shown on Fig. 19. This is called "mesh," or more often "delta" connection, and the three circuits here are between AB, BC, and AC.

It will be seen that both incandescent and arc lamps which require single-phase current, can be arranged on two or three phase circuits on any of the phases, while motors which work better with more than one phase can be supplied from all the phases. If, however, a single-phase load is supplied from a multiphase circuit, care should be taken to

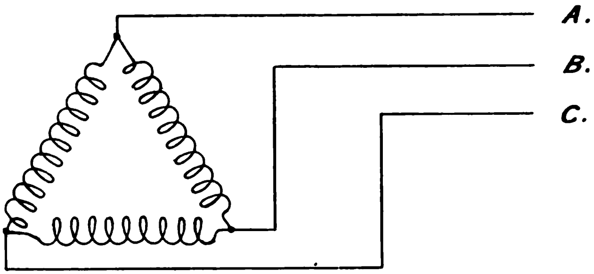

Fig. 19.—Method of Connecting up Three-Phase Mesh Wound Armature to Three-Wire External Circuit.

see that the load is balanced as evenly as possible between the phases.

Alternating current motors may be divided into three classes:—

(*a.*) Synchronous motors.
(*b.*) Induction motors.
(*c.*) Commutator motors.

Synchronous motors are convenient in special cases, but find little employment in ordinary industrial work. They are simply single or polyphase generators supplied with current at the correct voltage and periodicity. If excited to the same degree, and run up by external means to the same synchronous speed as the generator, the motor will continue to run in step with the generator whatever the load.

Should the motor be overloaded there will come a point where it will break out of step with the generator and stop altogether. The disadvantages of such a motor lie in the need for independent excitation of the fields, and the special means necessary for running the motor up to speed when starting. Unless fast and loose pulleys are provided

Fig. 20.—Squirrel Cage Type Induction Motor.

this may be a difficult matter. Their principal use is at the receiving end of transmission lines where stops are infrequent and the load is well within the full load rating of the motor. The term synchronous speed does not necessarily mean that the generator and motor speed are the same, but it is that speed per minute which multiplied by the number of pairs of poles in the motor gives a product equal to

the periodicity of the circuit per minute. Thus on a 50 ~ circuit the synchronous speed of a motor having four pairs of poles per phase would be :—

$$\frac{50 \sim \times 60 \text{ seconds}}{4 \text{ pairs of poles per phase}} = \frac{3{,}000}{4} = 750 \text{ revolutions.}$$

Fig. 21.—Slip Ring Type Induction Motor.

The induction type of motor is specially suitable for two and three phase circuits, though it can be used with satisfactory—if inferior—results on single-phase circuits.

Its general appearance is not unlike that of a direct current motor as shown in Figs. 20 and 21, which illustrate the standard patterns of the Electric Construction Co.'s

squirrel cage and slip ring types respectively. This motor is essentially a constant speed machine, special arrangements having to be made when variable speed is required. Both types consist essentially of two parts, the frame or stator and the rotating armature or rotor, and so far as the stator is concerned they are similar in appearance. It consists of a cast-iron frame which not only forms the

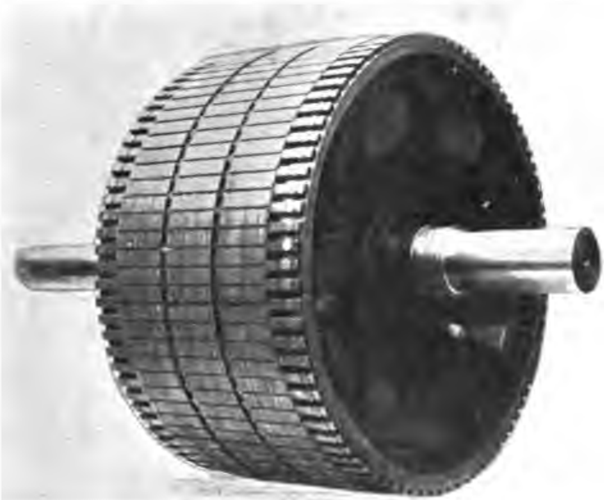

Fig. 22.—Rotor of Squirrel Cage Type Induction Motor, as made by the Electric Construction Co.

base for the motor but also supports the bearing brackets. The field magnet core is made up of laminated steel discs built into the frame, having slots cut in its face to receive the stator conductors. These carry the main current and consist of carefully wound coils well insulated both from each other and the core. The ends of the conductors are taken to the motor terminals. The rotor is different in the two types. Taking the squirrel cage pattern first, it will be

seen from Fig. 22 that it consists of a strong steel shaft having mounted on it a cast-iron spider to which is secured the laminated steel discs which form the core. The rotor winding consists of bars of copper placed in the core slots but insulated from them. They are connected at the ends to large gun-metal rings which effectively short circuit them. There are thus no moving contacts in the motor at all, the current supplied to the motor simply flowing through the stator coils.

There are the usual mechanical devices, such as oil ring lubrication and long bearing surfaces, which are necessary parts of any successful motor.

In the slip ring motor, the parts of which are shown on Fig. 23, the laminated steel core of the rotor is built up on the cast-iron spider as before. The conductors, however, consist of insulated coils placed in the core slots. There are usually three coils symmetrically spaced for three-phase currents and joined at the neutral point. The ends are taken through the hollow shaft to three slip rings placed outside the bearing on an extension of the shaft. These slip rings are insulated from the shaft, and conduct the currents generated in the rotor to the carbon brushes which are held in position by the brush holders as in direct current motors. Sometimes one of the slip rings is left uninsulated to ensure an earth connection. The use of these slip rings is to provide a means of introducing resistance on starting into the rotor circuit and so increasing its starting torque.

The stator windings in a three-phase motor are connected so that the different phases are symmetrically arranged, and the successive impulses or waves of current produce a rotating magnetic field, or rather the magnet pole due to the maximum rush of current is constantly moved forward as the current waves rise and fall in the different phases. So long as there is no movement of the magnetic field, there is no tendency on the part of the rotor to start, but the moving field causes the stationary

rotor conductor to cut the lines of magnetic force passing through the rotor core, and so generates a current in the

Fig. 23.—Parts of Slip Ring Type Induction Motor, as made by the Electric Construction Co.

rotor bars, which, when interlinked with the magnetic field, produces sufficient torque to cause the motor to start.

The speed of the rotating field depends upon the number

of pairs of poles per phase in the motor, and the periodicity of the circuit, thus with a 50 ~ single-phase circuit, the motor speed should be :—

With	6	poles, *i.e.*,	3	pairs,	1,000	revolutions	per	minute.
„	8	„	4	„	750	„		„
„	10	„	5	„	600	„		„
„	12	„	6	„	500	„		„

On a two-phase circuit the number of poles would be twice, and on a three-phase motor three times, as many as in a single-phase motor.

The actual speed of the motor must, however, be less than the above figures, since the number of magnetic lines cut, and consequently the amount of current flowing in the rotor coils, depends upon the difference between the speed of the rotor and that of the moving field. This difference is called the "slip" of the motor, and its value for ordinary sizes can be seen in the following particulars of standard motors listed by the Electric Construction Co. :—

Normal Full Load of Motor.	Periodicity.	Speed of Rotating Field.	Full Load Motor Speed	Slip in Revs. per Minute.	Per Cent. Slip.
3 B.H.P.	50 ~	750	690	60	8·0
5 „	„	1,000	935	65	6·5
9 „	„	600	555	45	7·5
12 „	„	750	710	40	5·3
15 „	„	600	575	25	4·1
18 „	„	1,000	955	45	4·5
25 „	„	750	725	25	3·3
30 „	„	750	730	20	2·7
40 „	„	600	580	20	3·3
50 „	„	750	730	20	2·7

The percentage slip decreases in general with the size of the motor. The above values are for the motors working

at full load, at light loads it is proportionally greater, and with slip ring motors, on starting with external resistance in the rotor circuit, it is sometimes very high indeed.

Another important quality in an electric motor is its ability to start under load. With squirrel cage wound induction motors it is possible to get full load torque or even more on starting, but only by taking from three to four times full load current in the stator circuit. With large size motors such rushes of current cause marked fluctuations in the pressure of the supply circuit, and if incandescent lamps are being supplied from the same system will cause them to flicker over a considerable area. For this reason many station engineers limit the permissible starting current to be taken by any induction motor connected to their mains to one and a third or one and a quarter times full load current, and sometimes forbid entirely the use of squirrel cage wound motors in all sizes above 3 or 5 B.H.P. This form of motor, however, by reason of the simplicity of its working parts, and the great advantage of having no commutator, brushes, slip rings, or any rubbing electrical contact, has so many advantages that it is worth every effort to extend its use. There is no doubt that the great success of the Newcastle-on-Tyne Electric Supply Co. in supplying power to the various industries on the banks of the Tyne is largely due to their enlightened policy in regard to these motors, no less than 3,000 to 4,000 horse-power of this type being connected with their mains, and their policy is being followed by others who are aiming at securing large power loads.

It is possible to reduce the starting current at the expense of reducing the starting torque, by using transformers to cut down the voltage of the stator current, but in cases where it is necessary for the motor to start with a reasonable current under full load, slip ring motors must be used.

In a two or three phase motor the rotating field is produced immediately the current is switched on, and it is therefore possible to make the motor start without further

apparatus. With single-phase circuits this is not the case, and special means have to be provided for starting the rotation of the field. When the motor has once started, the interactions of the stator and rotor circuits upon each other are sufficient to maintain the rotating field. Hence a necessary part of the single-phase motor starting equipment is what is termed a "phase-splitter," which is simply a special form of choking coil placed in one of the two parts of the stator circuit. In appearance like a small transformer—a coil wound round an iron core—it causes the portion of the current passing through it to lag a little in phase behind the rest of the current, and this difference of phase causes a sufficient displacement of the two parts of the stator fields to start the motor. This explains why the starting torque of single phase is inferior to that of two and three phase motors, and why they have to be fitted with fast and loose pulleys so that the load is only applied after the motor has been started. After such a motor has been started the "phase-splitter" may be short circuited.

It is important to note that it is easy to reverse the direction of rotation of an induction motor, the only thing needed being the crossing of one pair of the line wires.

The maximum torque which can be exerted by an induction motor depends upon its design and is largely affected by the clearance allowed between stator and rotor. As the conductor coils are in each case completely embedded in the core slots this clearance is often made very small indeed. If at any time the motor is so overloaded that it needs more than the maximum torque the motor will give at that speed, the motor will break out of step and stop altogether. The point at which this takes place, is determined when the motor is designed, and in medium-sized machines, of from 5 to 15 B.H.P., is usually about 150 per cent. to 200 per cent. of full load, and in larger sizes from 200 per cent. to 250 per cent. of full load. Though the maximum torque is the same whatever the resistance of the rotor circuit, there

are important relationships between the two, since the higher the rotor circuit resistance the greater the percentage slip and the greater the starting torque. Indeed, for all loads between zero and the rated full load of the motor, the slip is proportional to the rotor resistance, and consequently a high percentage slip means a large energy loss in the rotor and an inefficient machine when working.

It follows that a motor with a fixed rotor resistance, such as a squirrel cage wound machine, can only have a high efficiency when working if the internal losses, and consequently the starting torque, is small. This is found to be the case, and the conditions are not altered by the adoption of any special methods of starting, such as auto-transformers or "star to delta" switches. These improve the efficiency on starting by reducing the starting current taken from the line, but do not increase the starting torque.

The only solution of the difficulty is to make the rotor circuit variable, so that on starting its resistance may be high, and a good starting torque may be obtained, and later, part of the circuit may be cut out and the resistance thus reduced, with a corresponding improvement in the amount of slip and of efficiency.

This is done in slip ring motors, when, as shown in Fig. 23, means are provided for leading the rotor circuit outside the motor where its resistance may be varied at will. The circuits are taken from the brush holders to the terminals of the motor, and thence to the regulating resistances, which may be cut in or out by moving the regulator switch handle.

It should be remembered that the current in this circuit is only the low voltage induced current in the rotor conductors, and that it has no direct connection to the current supplying the motor which only flows through the stator circuit.

By suitably grading the external starting resistance it is, therefore, possible to control the starting torque, and consequently the starting current, in the stator circuit, and to obtain, if desired, two or three times full load torque on

starting, while, when working the external resistance is short circuited and the low resistance rotor enables the motor to work with a low percentage slip, that is with nearly constant speed with varying load, and at the same time have a high percentage efficiency.

Slip ring motors are naturally more expensive—usually about 20 per cent.—than squirrel cage machines and have not their simplicity and absence of running contacts, but they are very valuable in cases where high starting torque is required or where it is essential to vary the motor speed while working.

This is accomplished by leaving some of the rotor resistance continually in circuit, which, as explained above, increases the slip between the rotating field and the rotor. This method of speed regulation is, however, very wasteful, resembling that of speed control in direct current motors by the insertion of resistance in the armature circuit. Slip ring machines may, of course, be either one, two, or three phase, but it is customary to wind the independent rotor circuit for three phase, whatever the character of the supply.

Since the speed of an induction motor on a given circuit depends upon the number of poles, efforts have been made with some success to so wind the stator, that by altering the connections, the number of effective poles can be varied while the motor is at work. The Sandycroft Foundry Co., who work the Hunt patents, have made a speciality of this type of motor, and by means of two arrangements of connections for the stator, and both a fine wire and thick wire winding on the rotor, they have been able to improve the power factor when starting, and at the same time to minimise the slip at all loads. In some of their latest machines the slip has been as low as 1·2 per cent., while with motors of 50 B.H.P. size they find it possible to bring the slip down to 1 per cent. In these machines the high resistance winding is used to obtain high starting torque, and this winding becomes ineffective when, after starting, the stator

connections are altered, and the normal number of poles are used, the low resistance thick rotor conductors being brought into action at the same time.

Two or more definite speeds can be got by arranging the stator circuit so that different groupings giving different numbers of effective poles are obtained. It remains true, however, that an induction motor is best suited for working at one normal speed, and that hitherto most of the attempts to produce really efficient commercial variable speed motors have failed. It is usually advisable to try and arrange the drives so that the motor runs at its normal speed, and if different speeds are necessary, to use mechanical methods of varying the machine speed, or employ some other form of motor.

The past few years have seen great advances in the development of the single-phase commutator motor. This design has the advantage of high starting torque and easy regulation of speed at all loads. Most of the experimental work in connection with these motors has been done in connection with the application of single-phase currents for traction work, with the result that several tramways and railways on the Continent and in the United States are successfully using such motors. In this country they have been adopted by the Midland Railway Co. for their experimental nine miles of electric railway between Heysham and Lancaster, which has been in successful operation several months, and they are being installed by the London, Brighton, and South Coast Railway on the eleven miles of route between London Bridge and Victoria, which are being converted from steam to electric traction.

The single-phase commutator motor is similar in appearance to an ordinary series wound direct current machine, but the field magnets are laminated. The field magnets or stator have a thick coil winding round which the whole of the current supplied to the motor flows.

The rotor is exactly like a direct current armature with

its core, coils, commutator brushes, and brush gear. In some forms of this motor there is only one pair of brushes which are short circuited on themselves; in others an additional pair of brushes placed at right angles are added, and through this latter pair the stator current enters and leaves the rotor. If this is done, it slightly alters the characteristics of the machine, but the changes which take place are largely a matter for the designer.

These motors work best on low periodicity circuits, and in the large sizes of 50 and 100 B.H.P. used for railway work they are made for circuits of not more than 25 ~ per second. The difficulty in adapting them for 50 ~ circuits has been the excessive sparking at the commutator, but both Messrs Siemens and Brown, Boveri, & Co. have overcome this trouble, and are able to supply these motors up to 5 and 10 B.H.P. for 50 ~ circuits.

For traction work it is interesting to note that the same motors may be used both on direct and alternating current circuits. In fact, on one line in the United States, equipped by the Westinghouse Co., the motors are supplied with single-phase alternating currents transformed down to 230 volts on one part of the route, and when the cars reach the city limits, they receive direct currents from the ordinary direct current mains at 500 volts.

These motors may have their speed regulated in the case of motors having short circuited rotors by simply moving the brushes, or in the case of motors in which either the whole or part of the current passes through the rotor by varying the pressure of the rotor circuit by means of a variable ratio transformer.

The efficiency of this type of motor is good, its starting torque is comparable with that of a direct current series wound motor, and it is easy to regulate the speed. As the commutation troubles at 50 ~ are now being overcome, there should be a wide field for its use in industrial work. It is already being applied with marked success to driving ring

spinning machines in cotton mills, and it bids fair to revolutionise textile mill work. It is suitable also for cranes, hoists, and other cases where variable speed and high starting torque are required. These motors may be used on three-phase circuits by balancing them as far as possible on the separate phases.

They do not at present compare favourably in cost with induction motors of equal output, partly because their design is more expensive and partly because the active material in the motor is not so well utilised as in the polyphase induction type. The same rule as to reversing the direction of rotation by changing the connections in either rotor or stator holds with this motor as with the induction type.

CHAPTER III.

THE STARTING AND SPEED REGULATION OF ELECTRIC MOTORS.

Importance of Good Starting and Regulating Apparatus—Requirements of Good Motor Starters—"No Load Release" and "Overload Preventer" Attachments—Description of Typical Direct Current Motor Starters—Motor Panels—"Fool Proof" Starters—Switch Pillars—Description of Controllers and Controller Connections—Shunt Motor Speed Control—Series Motor Speed Control—Auto-Transformers for Alternating Current Induction Motors—Other Induction Motor Starting Devices.

THE starting and switching arrangements of a motor are an integral part of the electric drive, and if success would be attained, as much care and thought must be given to their design and construction as to the motor itself. Many of the failures which have in the past tended to discredit the use of electric motors have been due to obvious faults in the starters or regulators. So long as the motor seemed all right, little thought was given to its accessories, with the result that often, when the motor was most needed, it was useless because a wire in the starter resistance was broken, or a connecting screw had worked loose, and becoming hot, had burnt up the contact.

Fortunately, the fact that a chain is no stronger than its weakest link, and similarly that a motor drive equipment depends equally for its reliability, upon motor, starter, and regulator, has now been better realised, and during the past few years much attention has been given to the design and construction of motor accessories. Several firms have devoted themselves to their manufacture, and have pro-

duced good mechanical designs, comparable in reliability to the valves which are so necessary a part of a steam engine installation.

When an electric motor is started there is a rush of current through the armature, due to the absence of any opposing or counter electrical pressure in the motor armature. This opposing pressure, referred to on page 31, is caused by the rotation of the armature in the magnetic field of the motor, and so cannot be exerted until after the field has been built up, and the motor armature has run up speed.

The torque or starting moment of the motor may be expressed as the product of the current flowing in the armature into the magnetic strength or field of the motor, consequently to get full torque or starting moment—a necessary condition on starting a motor—the fields must be fully excited, and the full load current must flow through the armature.

The conditions to be met in starting a direct current motor are therefore arrangements for fully exciting the field magnets and the provision of such an amount of external resistance in the armature circuit that, without the aid of any opposing electrical pressure, the current flowing cannot exceed either full load current or some previously determined value which is not injurious to the motor. As soon as the motor starts, it begins to generate an opposing electrical pressure, so that the starting resistance may gradually be reduced until, when the motor has reached full speed, it has all been cut out of circuit.

In a series motor the passing of full load current through the armature and field magnet coils at once gives full load torque. In a shunt wound motor, where the field magnet circuit is independent of the armature circuit, it is not enough to pass full load current through the armature—the field circuit must first be closed, and time allowed for the field magnets to build up their full strength.

After the motor has started, provision must be made in the starter for resistance to be gradually cut out, so that approximately full load current shall be maintained flowing through the armature coils. Gradually, the resistance to the flow of current through the armature is transferred from the actual electrical resistance of the wire in the starter, to the counter electrical pressure generated by the rotation of the motor armature, until as the motor attains full speed the starting resistance is entirely cut out.

It is, however, of the greatest importance that means should be provided for reinserting the whole of the starting resistance, should the motor for any reason stop running; for, if the motor is at rest and the current is switched on without the resistance being in circuit the sudden excessive rush of current will burn up the armature conductors.

The starting resistance must be able to carry the full load current of the motor for short periods. The various sections of the resistance—usually about ten in number—are connected to the contacts of a multiple point switch, so that the cutting out of successive sections of the resistance is effected by moving a switch handle from contact to contact. A sufficient pause should be made on each step to permit the motor to attain its correct speed under those conditions, especially when the motor is starting under load.

Since all the armature current flows through the resistance, a considerable amount of heat will be generated, and effective means must be provided for dissipating it, or the starter will be damaged. For a long time sufficient attention was not paid to this point. Iron or other high resistance wires were used of small size compared to the currents to be carried, and these when heated in air soon became brittle, especially if the motor had to be started several times in succession before the resistance had time to thoroughly cool down. Under such circumstances faults were almost certain to occur.

A good starter should allow a motor to be started up

under full load at least every half hour without getting too hot, the time required for the start being about half a minute, and if users would insist on such a test being applied in their presence a dozen times before the motor starter was accepted, they would ensure getting a sound and reliable article.

Since all starting resistances are designed for the passage of the current through them for short periods only, it must be understood that if the switch handle is stopped on any

Fig. 24.—Messrs Siemens' Standard Pattern Direct Current Motor Starter.

of the intermediate contacts longer than necessary, the starter is very liable to be damaged by being burnt out.

The following descriptions of starters should be taken as typical rather than exhaustive; they, however, indicate the direction along which the law of "the survival of the fittest" has for some time been operating.

Fig. 24 shows a standard which has been developed by Messrs Siemens for motor starters and for shunt regulators for large dynamos. The resistance consists of a long strip of thin sheet iron bent into folds with pieces of mica between

the convolutions for insulating purposes. These folds are tightly packed into troughs made of micanite or other infusible material, and are placed in a cast-iron box. At intervals, plates of copper are placed between the sheet-iron bends, and serve as tappings for the switch contact connections. A slate panel is fitted to the front of the case on which the switch contacts are mounted.

The switch arm is held in the off position against the rubber stop with all resistance in circuit, by a spring enclosed under the hand-wheel. On turning the hand-wheel the switch arm in passing over the first contact completes the shunt field circuit, and so energises the field poles of the motor and also the poles of the no load release coil—shown to the right of the diagram—which is included in the same circuit. The armature circuit is completed as the switch arm passes over the next stop, and the motor starts with all resistance in circuit, gradually increasing in speed as the resistance is cut out by the passage of the switch arm over successive contacts. When all resistance is cut out, the soft iron bar secured to the side of the switch arm presses against, and is attracted by, the magnetised poles of the no load release coil as long as the motor is working. Should the field current of the motor from any cause be interrupted, the no load release coil will be demagnetised, the switch arm will no longer be attracted, going back, under the influence of the spring, to its normal position against the rubber stop with all resistance in circuit.

Fig. 25.—Messrs Electromotors' Direct Current Motor Starter.

The coil to the left of the illustration is the overload release which is in series with the armature circuit. If the

armature current becomes excessive, the hinged soft iron bar underneath the coil is attracted, and bridges two contacts which short circuits the no load release coil, causing it to become demagnetised, and to stop the motor by releasing the switch arm. Raising the knob at the bottom of the switch does the same thing if for any reason it is desired to stop the motor.

In the printing press controller described on page 242, the same principle of short circuiting the no load release coil is used to permit the motor being stopped from several points on the printing press remote from the actual controller.

Fig. 26.— Messrs Electromotors' Motor Starter, combined with Messrs Berry Skinner's Double Pole Switch Fuse.

The soft iron bar of the overload preventer (Fig. 24), when raised also engages a ratchet on the boss of the switch arm, and prevents its further movement until the speed of the motor has reduced the current to its normal value. This prevents the motor being started too quickly, and saves the armature coils from damage through excessive current.

In Fig. 25 we have the standard pattern of motor starter fitted with no load release coil and overload preventer made by Messrs Electromotors Ltd., of Manchester, and in Fig. 26 the same type of starter fitted with a cast-iron cover and combined with a double pole switch fuse in cast-iron box made by Messrs Berry, Skinner, & Co. This pattern of switch fuse has a quick break, and is very largely used in motor work. In this type of starter the resistances are made of wire kept cool by allowing ample ventilation spaces. The contact strips on the front of the switch are easily renewable when worn or burnt out. The action of the no load release

coil and overload preventer is similar in principle in all these starters.

Messrs Reyrolle & Co. use as a resistance material thin plates of an infusible compound, which, like carbon, has a lower electrical resistance when heated. The result is that when the switch arm is put on the first contact of the resistance, the motor starts, and as the material gets hot its resistance falls, and the current gradually increases until the motor has partly run up to full speed. The handle is then

Fig. 27.—Messrs Reyrolle's Direct Current Motor Starter.

further turned, and the resistance gradually cut out. This form of starter has successfully withstood very severe usage.

Fig. 27 shows its standard form, in Fig. 28 it is enclosed in a watertight case for use in very damp positions, and in Fig. 29 mounted on a panel with a quick break, main double pole knife type of switch and separate fuses. Fig. 30 shows one of these resistances combined with a double pole switch and fuse made up in the form of a drum type controller specially for outdoor and rough use. The drum cylinder can move independently of the hand-wheel, and the starter

is fitted with overload preventer and no volt release coil. When in use the starter is protected by a sheet-iron cover.

The Adams Manufacturing Co. are another firm who have made a speciality of motor starters, and have perfected a number of types. One of these (Broadbent's Patent Automatic Control) is illustrated and described in the section relating to printing machines (page 242). In one type termed "the one-minute pattern," the resistance is

Fig. 28.—Messrs Reyrolle's Watertight Direct Current Motor Starter.

so proportioned that the starting current shall not exceed 50 per cent. above full load current, a maximum period of forty seconds being allowed for cutting out the resistance. In other types the moving of the switch is controlled through worm gear operated by a side handle. The necessity for turning the handle a large number of times to operate the switch arm ensures that the switch shall not be moved too rapidly over successive resistance contacts.

The Electric and Ordnance Accessories Co. also make

several patterns of thoroughly serviceable starters, one of which, called the "Autograd" and shown in Fig. 31, has some special features. The handle and switch arm are separate, the handle being attached to the no load release coil, which can be moved about the same

Fig. 29.—Messrs Reyrolle's Motor Starter, combined with Double Pole Switch and Separate Fuses.

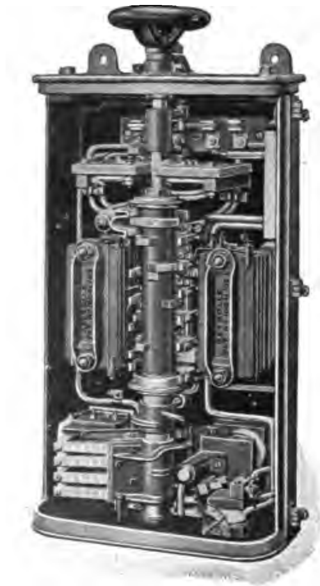

Fig. 30.—Messrs Reyrolle's Drum Type of Combined Double Pole Switch and Direct Current Motor Starter.

centre as the switch arm. Current is passed to this coil from the lower rings shown in the illustration. The switch arm is normally in the off position to the left, while another spring

at the back of the slate keeps the handle with the no volt release coil in the extreme right position. To start the motor, the handle is moved towards the left, in passing over the contact strips, the no volt release coil is energised, and when it reaches the switch arm it attracts and holds the soft iron plate attached to its side. The handle is now released, and under the influence of the spring at the back of the slate the handle and no volt release coil

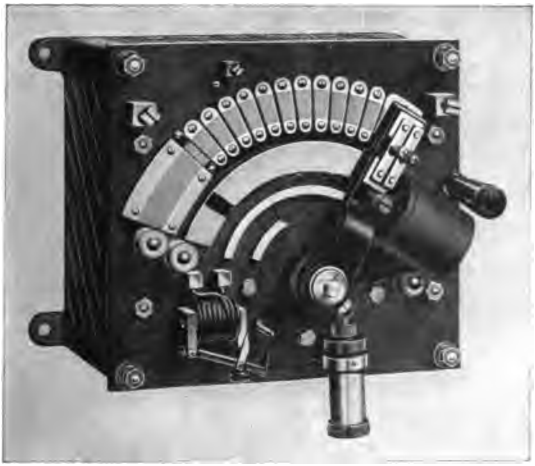

Fig. 31. —The "Autograd" Direct Current Motor Starter.

move back taking the switch arm with them, thus cutting out the starting resistance. The action of the dashpot is to retard the movement of the switch arm, and so ensure slow but steady cutting out of the resistance coils; while, if anything happens to the motor, either from overload or failure of current, the no volt release coil is de-energised and releases the switch arm, which at once returns to its normal position with all resistance in circuit. Such a switch is to a large extent automatic in action and free from possible

trouble caused by the forgetfulness of workmen to move the handle of the starter slowly.

Quite a number of designers have brought out these "fool-proof" patterns of starters, a few of which have proved

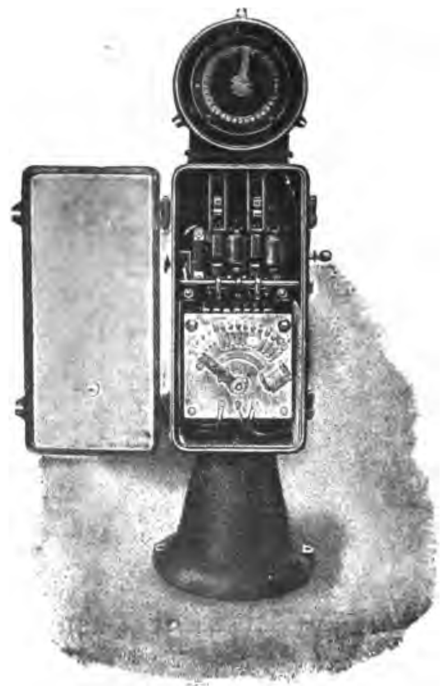

Fig. 32.—The British Westinghouse Co.'s Direct Current Motor Control Pillar.

successful. Perhaps the most practical form is to have some variety of the loose handle type with a weight lifted against gravity, controlled in its fall by a dashpot. In this way a slow steady movement of the switch arm is ensured quite independent of the movement of the handle.

It is sometimes more convenient to mount the motor control apparatus in a cast-iron pillar, and Fig. 32 shows the form adopted by the British Westinghouse Electric and Manufacturing Co. A double pole switch and fuse is mounted above the starter, and there is also provided

Fig. 33.—Liquid Motor Starter as made by the Sandycroft Foundry Co. Ltd.

a circular multi-contact switch for regulating the speed of the motor by inserting resistance in its field circuit.

The Sandycroft Foundry Co. Ltd. have worked for some time in developing liquid types of motor starters, and Fig. 33 shows one of their latest patterns combined with a high tension switch for either breaking the circuit or for

use when reversing the direction of rotation of the motor. This switch can only be operated when the resistance switch is in the off position, and the switch control handle is locked until the main switch has been pushed well home.

In this type of starter the resistance consists of water

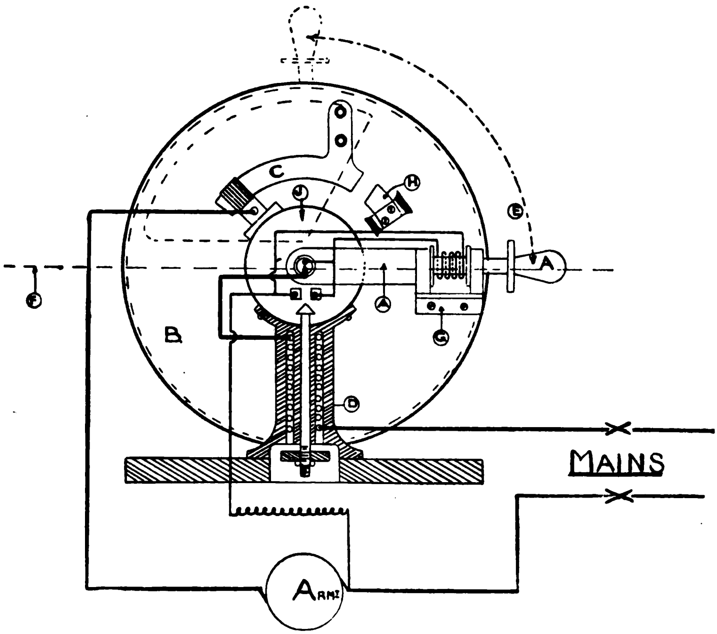

Fig. 34.—Diagram of Connection of a Liquid Motor Starter as made by the Sandycroft Foundry Co. Ltd.

having a little soda or other suitable substance in solution. The passage of a current of electricity heats the liquid, and if it is required to keep the resistance in circuit for any length of time, means must be provided for a constant circulation of the liquid.

The general action of this type of starter is illustrated

in Fig. 34, which shows the connections for a direct current shunt wound motor starter. B is a cast-iron drum for holding the liquid, which can be rotated in insulated bearings. Fixed to this cylinder, but insulated from it, are blades which dip into the liquid to varying depths when the drum is rotated, so varying the resistance in circuit. When the motor is fully started the contact H cuts the resistance entirely out of circuit. Current is supplied to the blades during rotation of the drum by the contact pieces C.

The drum may be moved through a right angle by the handle A which is connected to it, through a catch G. The no volt release coil in series with the field circuit of the motor is wound on a core connected to the handle A. When current is flowing through the motor the no volt release coil is magnetised and holds the catch G so that the drum moves with the handle A. Should the circuit be interrupted the no volt release coil is demagnetised, the catch A released, and the drum falls by gravity into its normal position with all resistance in circuit. If the motor is overloaded the plunger inside the pedestal D is drawn up into the overload preventer coil and short circuits the no load release coil, thus stopping the motor.

If means are provided for changing the solution as it gets hot, the current may be kept flowing through it for considerable periods so that the apparatus acts as a controller as well as a starter, and by carefully insulating the several parts, and connecting the drum to the water supply through lengths of rubber tubing, it may be made suitable for use with high tension circuits.

For cases where the motor is required to be constantly started, stopped, and restarted in the opposite direction, as well as run at varying speeds for short periods, starters and regulators of what are known as the controller type are nearly always used.

These controllers consist of a cylinder mounted on a vertical axis carrying a number of contacts which are

successively brought into circuit as the handle is moved round. These controllers are universally employed in tram-car work where two motors are generally employed, the changes in speed being obtained by so altering the connections that the motors run either in series or parallel with each other, intermediate points being obtained by inserting resistance in series with the motor armatures. Controllers of this type are also used for single motor working of cranes or machine tools.

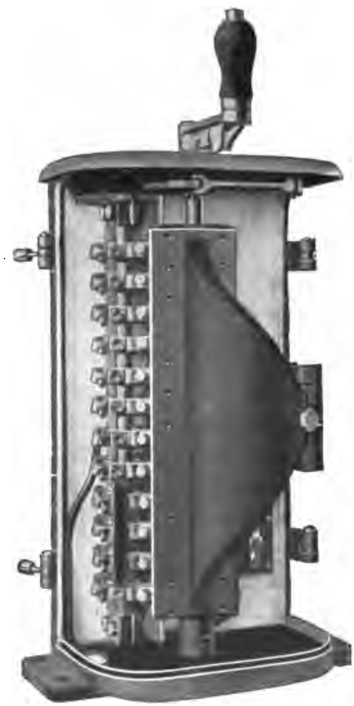

Fig. 35.—The Electric and Ordnance Accessories Company's One Motor Crane Controller.

Fig. 35 shows a controller for crane work made by The Electric and Ordnance Accessories Co. Ltd., and Fig. 36 a diagram of the connections. It is for use with a series wound motor, and has five running points in either direction but no provision for an electric brake.

It should be remembered that to reverse a series wound motor it is only necessary to change the direction of flow of the current through the armature, keeping it in the same direction through the field coils.

In this diagram—M represents the motor armature.
SF „ motor field coils.
R „ starting resistance.
L „ line.
B „ blow out coil.

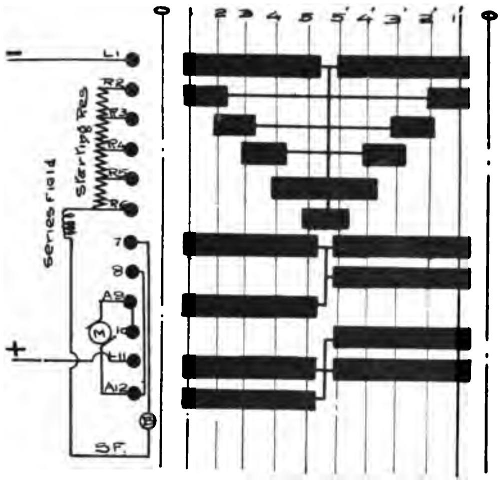

Fig. 36.—Diagram of Connections for above Crane Controller.

The current path on successive contacts may be traced as follows, starting from the – or negative terminal :—

Contact 1.—All starting resistance in circuit—
$L_1 - R_2 - 7 - A_9 - M - A_{12} - L_{11}$.

Contact 2.—Part resistance out—
$L_1 - R_3 - 7 - A_9 - M - A_{12} - L_{11}$.

Contact 3.—More resistance out—
$L_1 - R_4 - 7 - A_9 - M - A_{12} - L_{11}$.

Contact 4.—More resistance out—
$L_1 - R_5 - 7 - A_9 - M - A_{12} - L_{11}$.

Contact 5.—All resistance out—
$L_1 - R_6 - 7 - A_9 - M - A_{12} - L_{11}$.

There is a stop here, and to reverse the motor it is necessary to turn the handle in the opposite direction, re-insert all the resistance, and proceed to

Contact 1′.—All starting resistance in circuit—

$L_1 - R_2 - 7 - 8 - M - 10 - L_{11}$.

The motor revolves in the opposite direction since the current in the armature circuit only is reversed.

Contact 2′.—Part resistance out—

$L_1 - R_3 - 7 - 8 - M - 10 - L_{11}$.

Contact 3′.—More resistance out—

$L_1 - R_4 - 7 - 8 - M - 10 - L_{11}$.

Contact 4′.—More resistance out—

$L_1 - R_5 - 7 - 8 - M - 10 - L_{11}$.

Contact 5′.—All resistance out—

$L_1 - R_6 - 7 - 8 - M - 10 - L_{11}$.

The blow out coil is in series with the circuit, and produces a magnetic field between the controller case and the divisions between the contacts. The circuits are thus broken in a magnetic field, and the sparking is thereby reduced to a minimum.

If further contacts are added by which the connection of the circuit to the line can be completely broken, and the armature is so connected to the field circuit that the current flows through the field coils in the reverse direction, the combination acts as an efficient electric brake. This is found very useful in many cases. In Fig. 37 we have the connections shown for a controller similar to that already described, but with two additional braking contacts.

Here A	represents the	motor armature.
SF	,,	motor field coils.
R	,,	starting resistance.
L	,,	line.
B	,,	blow out coil.
SB	,,	solenoid brake.

On starting, the handle of the controller is moved from 0 across contacts 2 and 1, which do not make contact as the circuit is interrupted at 13, to the normal stopping point for the handle, also marked 0.

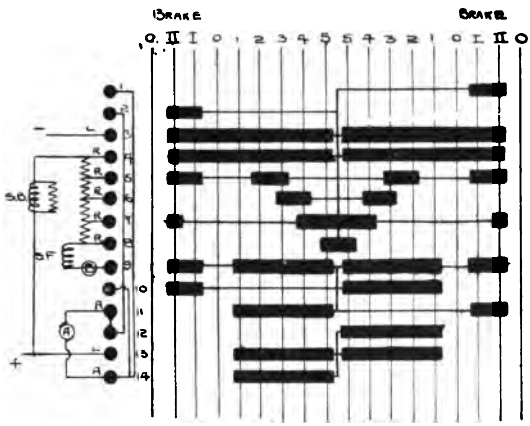

Fig. 37.—Diagram of Connections of Crane Controller, with Electric Brake.

The succeeding connections starting from the – or negative terminal are :—

Contact 1.—All starting resistance in circuit—
$L_3 - R_4 - SF - B - 9 - A_{11} - A - A_{14} - L_{13}$.

Contact 2.—Part resistance out—
$L_3 - R_5 - SF - B - 9 - R_{11} - A - A_{14} - L_{13}$.

Contact 3.—More resistance out—
$L_3 - R_6 - SF - B - 9 - R_{11} - A - A_{14} - L_{13}$.

Contact 4.—More resistance out—
$L_3 - R_7 - SF - B - 9 - R_{11} - A - A_{14} - L_{13}$.

Contact 5.—All resistance out—
$L_3 - R_8 - SF - B - 9 - R_{11} - A - A_{14} - L_{13}$.

To apply the electric brake the handle is rapidly brought back to position 0, where all the resistance is in circuit, and then moved to

Brake Position I.—The motor is now disconnected from the line at 13, and the circuit runs from the motor armature A (top brush) to contact finger 2, thence to R_5 – through the resistance to SF, B – contact 9 – contact 10 – back to the lower brush of the motor armature.

If a more powerful braking effect is required, the handle is moved to

Brake Position II.—Where the path of the circuit is the same as for Brake Position I., except that two sections of the resistance are cut out, contact being made at R_7 instead of R_5.

For running in the reverse direction the circuits are :—

Contact 1′.—$L_3 - R_4 - SF - B - 10 - A - A_{12} - L_{13}$.
Contact 2′.—$L_3 - R_5 - SF - B - 10 - A - A_{12} - L_{13}$.
Contact 3′.—$L_3 - R_6 - SF - B - 10 - A - A_{12} - L_{13}$.
Contact 4′.—$L_3 - R_7 - SF - B - 10 - A - A_{12} - L_{13}$.
Contact 5′.—$L_3 - R_8 - SF - B - 10 - A - A_{12} - L_{13}$.

It will be noticed that in all the running positions the solenoid brake SB is in circuit as a shunt to the resistances.

The braking connections for reverse running are :—

Brake Position I′.—Lower brush of motor armature to contact 1, thence R_5, through resistance SF – B – to contact 9 –, thence R_{11} to top brush of motor armature A.

Brake Position II′.—As for Brake Position I′., except that two sections of the resistance are cut out, contact being made at R_7 instead of R_5.

When controllers are used with shunt or compound wound motors, it is possible to control the speed within

wide limits by varying a resistance placed in series with the field coils, and, as the current is very small, a large number of contact fingers may be arranged, giving a very close variation.

It is also possible where a three-wire system of distribution is available to make use of two voltages such as 220 and 440 volts, and in this way to obtain a wide variation of speed. The motor is first started on the lower voltage, and run up to normal speed at that voltage; the resistance is again inserted, the field fully excited, and the motor armature then switched across the higher voltage, after which, by successive reductions of resistance, the motor is gradually brought up to its higher normal speed.

In Fig. 38 we have the connections shown for a shunt wound motor controller arranged for running on either a 220 or a 440 volt circuit with forty different speeds. This controller, however, is only designed for a motor running in one direction. The connections are:—

Off Position.—Brake magnet excited. Brake lifted. Shunt resistance connected across solenoid brake.

Position No. 1.—Brake magnet excited. Brake lifted. Shunt excited across 440 volts with no resistance in winding, thus giving maximum strength of field. Armature in series with all resistance in.

Positions Nos. 2 *to* 6.—As for No. 1, but with portions of armature resistance gradually cut out till at No. 6 all is out.

Positions Nos. 7 *to* 26.—Resistances are gradually inserted in shunt circuit, otherwise connections as No. 6. This weakens the field and consequently increases the speed.

The next operation must be made quickly. First short circuit the shunt resistances, and then moving over two contacts all the armature resistance is inserted, and the armature is switched across the 440 volt mains. This accounts for positions 27 and 28.

Position No. 29 cuts out part of the armature resistance, No. 30 the remaining part, and we then have the

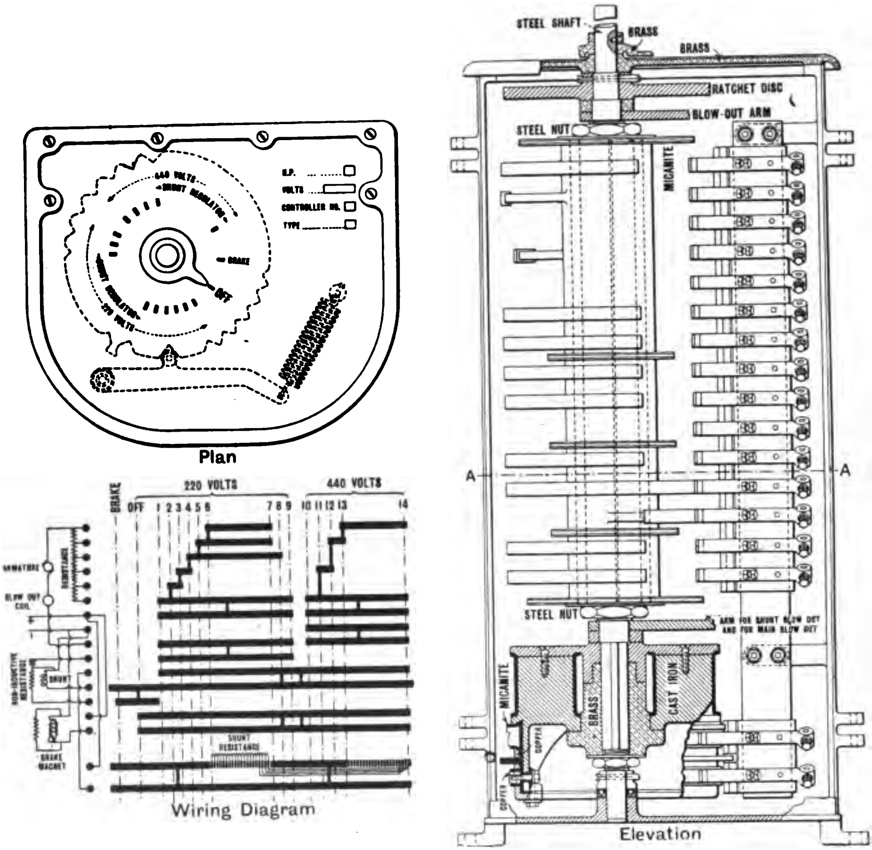

Fig. 38.—Diagrams of Direct Current Motor Controller for Three-Wire System, using Two Voltages.

twenty shunt regulating contacts repeated, until at last both the weak field and the armature are on the higher voltage circuit.

In such a controller it is usual to control the speed by the use of the shunt resistance contacts only. Special means are taken to reduce sparking, and non-inductive resistances are placed across the shunt coils to prevent damage when the field circuit is broken. A contact is also provided to allow a magnetic brake to be attached if desired.

There are, however, many cases where series motors are used in which this method of speed regulation is impossible, and resource must be made to the more wasteful method of inserting resistance in the armature circuit. Where this is necessary, great care must be taken to employ a resistance material which will not rapidly deteriorate when hot, and also means for dissipating the amount of heat generated when large motors are thus controlled. Fig. 39 shows a type of motor speed controller of this type made by The Electric Controller and Supply Co., who have made a speciality of this class of apparatus.

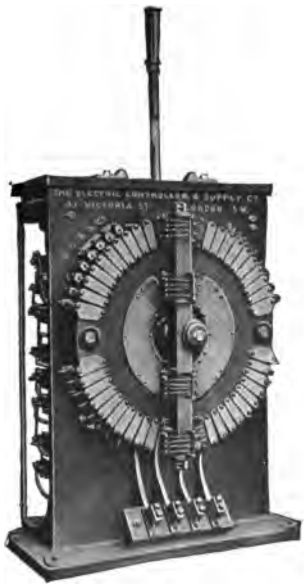

Fig. 39.—Large Motor Controller as made by the Electric Controller and Supply Co.

The switch arm is operated by moving the handle to and fro, and it will be seen that to reverse the direction of rotation of the motor the handle has to be moved past the off position, thus inserting all the resistance. The form of grid resistance, which is often made of a special quality of cast iron, and the method of arranging them in the frame so as to ensure ample ventilation, is shown in Fig. 40. A

magnetic blow out is provided to reduce the spark on changing contacts. This type of controller is very suitable for heavy work where large motors have to be run at varying speeds in either direction for short periods of time.

There are other methods of speed control, some of which are referred to on page 246, where speed regulation is effected by introducing opposing electrical pressure from another dynamo to vary the effective pressure at the terminals of the working motor. The details of these systems are very interesting, but for the most part they are only commercially used in special cases.

Fig. 40.—Form of Resistance Grid used by the Electric Controller and Supply Co.

When alternate current motors have to be dealt with, the conditions to be met are of a different character. In motors working on two or three phase circuits the rotary field is produced immediately the current is switched on, so that it is possible to start such machines without any further apparatus. As explained, however, in Chapter II. (page 49), this is inadvisable on account of the excessive rush of current which in many cases is detrimental to the general supply from the entire system.

This sudden rush of current can, however, be reduced if what is termed an auto-transformer is used to reduce the pressure at the motor terminals. This consists of a small

transformer with one set of windings placed across the line wires, as shown for a three-phase circuit on Fig. 41. Connections may be made to this set of windings at certain points, and the voltage of the current thus taken, depends upon the ratio of the number of turns in the small circuit to the total number of turns. In this way a large current at low voltage may be supplied to the motor, while the demand

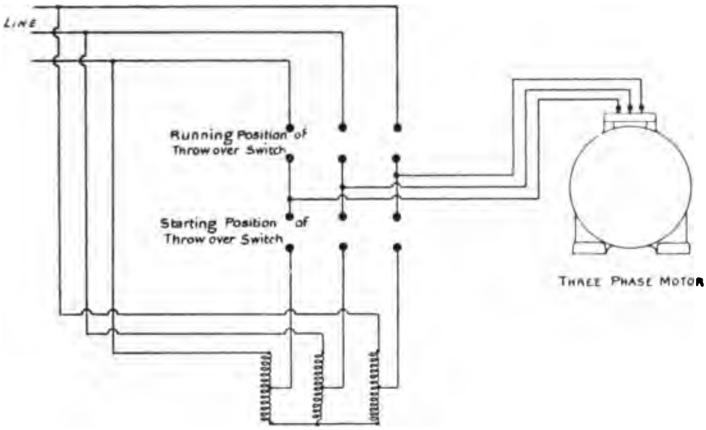

Fig. 41.—Diagram showing Connection of Auto-Transformer for Three-Phase Induction Motor.

on the line is only equal to a correspondingly reduced current at the line voltage.

It is usual to arrange that several tappings are made to the windings, and trial is made as to the best ratio to use, the voltage at the motor terminals being often about one-third of the line voltage. The power factor of the motor working at this low pressure is not so good as when supplied at the full load pressure, so that the effect of the increased starting current is not proportional to the ratio of the transformer windings.

For this reason the auto-transformer is taken out of circuit as soon as the motor is started. Figs. 42 and 43 show two patterns of auto-transformer with switches which have been designed by the Electric Construction Co. Ltd. In Fig. 42 the auto-transformer is at the back of the slate panel. In Fig. 43 it is placed above the switch, which is of the barrel type, having three contacts, namely, "off position" when the motor is disconnected from the line; "starting position" when it is connected with the auto-transformer in circuit, and the motor is consequently supplied at the lower voltage; and "running position" when the motor is supplied direct from the line, the auto-transformer being cut out of circuit. In Fig. 42 an ammeter to indicate the current actually taken by the motor as well as a pair of fuses are also mounted on the panel.

Fig. 42.—Auto-Transformer, with Switch and Fuse for Induction Motor.

Within certain limits it is possible to reduce the starting current by increasing the rotor resistance at the expense of increasing the "slip" of the motor. This is sometimes done by making the short circuiting ring of the rotor, of brass or of some metal of higher resistance than copper. This plan was effective in a case which came under the writer's notice a year or two ago, where it was necessary to reduce the starting current of a two-phase 40 B.H.P. 200 volt 50 ~ squirrel

cage motor as low as possible. The motor was direct coupled to a dynamo which was always open circuited on starting, so that the motor started light. After preliminary tests and fixing a brass rotor ring, it was found that with the auto-transformer adjusted to its best value of about 70 volts, the current required to be taken from the line to start the motor was only 40 per cent. of the rated current at full load, a result that compared favourably with some slip ring motors of the same size supplied from the same system.

Fig. 43.—Auto-Transformer, with Switch and Fuse for Induction Motor.

It is, however, usual for makers to ask either for full load or full load and a quarter current as that required to start a squirrel cage motor without load. If full load torque is needed, the current will be three to four times full load current.

It has already been noticed in Chapter II. that three-phase circuits may be either "star" or "delta" wound, and the two methods are illustrated in Figs. 17 and 19 (pages 41 and 42), where Fig. 17 shows a "star" wound and Fig. 19 a "mesh" or "delta" wound circuit. It does not affect the working of the motor which method is used, but a constant line voltage gives different pressures per phase with the two windings, the pressure per phase in the case of the "delta" winding being only 58 per cent. $\left(\frac{1}{\sqrt{3}}\right)$ of that with the

"star" winding. This has suggested what is called the "star" to "delta" method of starting, which, however, is only suitable for small motors or special cases. Here the three-phase windings of the stator are connected to a throw-over switch in such a way that when the switch is on one set of contacts the stator is "star" connected to the line, and when thrown over to the other set of connections "delta" connected. This arrangement is similar in effect to using an auto-transformer with a 58 to 100 ratio of transformation.

Fig. 44.—Single-Phase Slip-Ring Induction Motor Starter.

Instead of using an auto-transformer it is possible to cut down the line pressure by resistances placed in each of the phases of the supply circuit, and altering these as required by means of a three-arm multiple switch.

It is also possible to place a friction coil clutch or a fast and loose pulley between the motor and the driven shaft, and so enable the motor to be run up to speed before the load is put on. When this can be done, squirrel cage motors may be used without an excessive starting current being taken from the line.

Where slip ring motors are used, the starting current may be controlled by placing resistance in the low voltage rotor circuit, as already explained in Chapter II. (page 46). By this means it is possible to combine high starting torque on starting with small slip, and high efficiency when working.

These starting resistances are very similar in form to those used with direct current motors, the resistances being divided into three to suit the different phases, and the switch having three arms placed 120° apart, so that resistance is cut out of each phase simultaneously. It is usual in slip ring motors to wind the rotor for three-phase currents whatever the number of phases in the supply circuit.

The method of connecting up such a resistance is shown on Figs. 44 and 45, which show the starter designed by the British Westinghouse Co. for this class of motor. This is primarily intended for single-phase motors so that the "phase-splitter" referred to on page 50, Chapter II., is included, and the centre arm of the main switch is arranged to open automatically when the switch arm reaches the last position, and so throw the phase-splitter out of circuit. A starter of this type is suitable for motors up to about 15 B.H.P. size, and forms with its main switch and iron cover a convenient pattern for many purposes.

Fig. 45.—Single-Phase Slip-Ring Induction Motor Starter with Cover.

Reference is made in Chapter XIV. to the requirements of the Home Office that double pole quick break switches and fuses should be provided for each motor circuit, and in Figs. 26 and 29, two types of motor main switches are

illustrated. The fuses for motor circuits are often enclosed in groups in cast-iron cases, and Fig. 46 shows a useful pattern of ventilated switch fuse of the Reyrolle pattern for this purpose arranged to protect nine circuits fed from a common omnibus bar, the whole being enclosed in a cast-iron case.

The overload preventer, forming part of many starters, with its quick and certain action, is in some cases found to be a disadvantage. A motor may have to overcome a momentary overload, and the protective arrangements, if too sensitive, may do more harm than good. What is needed, is something, which, in the event of an overload being continued for such a period as to really damage the motor, will act without fear of failure, but which will permit of an overload for a short time without coming into operation.

Fig. 46.—Motor Fuse Distribution Board.

To accomplish this some people prefer to employ ordinary metal fuses rather than the electro-magnetic overload preventer. It takes a certain time to heat the metal to fusing point, and in this way stoppage of the motor due to momentary overload is to a large extent prevented.

What are termed, time-lag devices, have been suggested for the same purpose, one of the most successful consisting of a cylinder with a close fitting metal plunger dipping into a shallow bath of oil. This plunger is attached to the core of the solenoid which operates the switch, and should an

overload occur, the plunger has to be withdrawn from the cylinder, sufficiently to break the film of oil between the plunger and cylinder before it is free to operate the switch.

The time taken to free the plunger from the retarding influence of the oil film, depends upon the strength of the pull, which is regulated either by the strength of the current or the distance of the core in the solenoid. By suitably adjusting this distance it is possible to arrange that on an overload of 50 per cent. the cut-out release shall not act for say fifteen seconds, or on a 100 per cent. overload for five seconds, while on a 200 per cent. overload the pull is so violent that the oil film is at once ruptured, and the cut-out acts at once.

CHAPTER IV.

THE RATING AND EFFICIENCY OF ELECTRIC MOTORS.

Necessity for Employing Electric Motors to Best Advantage—Need for Standardisation—Engineering Standards Committee—Their Proposals as to Voltage, Periodicity, and Speed—Relation of Size and Output of Motors to Temperature Rise—Motor Tests—Percentage Efficiency—Methods of Test—Relation of Mechanical, Electrical, and Thermal Units to each other—Comparison of Efficiencies and Currents required by Direct and Alternating Current Motors.

WHILE it is a comparatively easy task to show that in many cases, the electrical is better and more convenient than the purely mechanical drive, it is often more difficult to prove that its adoption will prove a financial success. This is especially the case, when the cost of effecting the change is considerable, and the new method of working has to earn sufficient extra profit to pay a fair rate of interest on the new outlay, as well as on the capital already spent in connection with the mechanical driving arrangements, and even then show a sufficient balance on the right side to induce the manufacturer to make the alteration. To attain this end, the special conditions of any given case should be studied, in order that the motors may be used to the best advantage. It is also necessary to carefully choose the motors, and to do this, not only the first cost, but the rating and efficiency under working conditions must be considered. These qualities largely affect the cost of maintenance and often determine whether the installation is a success or failure.

It has long been felt, that one of the causes of the apparent non-success of British electrical manufacturers to earn satisfactory profits has been their willingness to try and please each individual customer, at the expense of making alterations to standard designs. The many voltages and periodicities in use, also stood in the way of the adoption of uniform patterns. At the same time this multiplicity of types prevented the cost of manufacture being reduced to what should be its normal figure; and the cost of the home-made article either prevented its adoption, or allowed a foreign-made, cheaper, and often less efficient article to be sold in its place.

This unsatisfactory state of affairs caused the question to be referred at the end of 1903 to the Engineering Standards Committee for consideration. This Committee was jointly composed of representatives of the principal Scientific Institutions and of the leading manufacturers and principal buyers of engineering plant and accessories. Its duty was to see what could be done to advance the welfare of the industry and the prosperity of the country by an endeavour to standardise the principal articles used in engineering work. This Committee appointed an influential Sub-Committee to deal with the matter so far as it concerned electrical generating plant, motors, and transformers. This Sub-Committee issued an interim report in July 1904, and a further one in 1907. In these reports they made certain recommendations with regard to voltages, periodicities, and speeds which have fortunately been embodied to a large extent in recent practice. They have also proposed limiting temperature rises under specified conditions, which, if acted upon, will ensure the rating of the motor being kept within safe limits.

The present position is that many manufacturers have directed their attention to the standardisation of their sizes and designs, and in motor work this has borne good fruit. The British article can be produced as cheaply as, and in many cases cheaper than, its foreign competitor, whilst its

mechanical and electrical qualities are equal and often superior.

The standard pressures which have been recommended for general use are 110, 220, and 440 volts for lighting and power work, and 500 volts for traction, an extra 10 per cent. being allowed in each case for losses between the lamp or motor terminals and the generator. In the case of three-phase circuits where lamps at 220 volts pressure are used between one of the conductors and the earthed neutral (see Fig. 18, page 41), the voltage between successive phases for motor work will be 220 volts $\times \sqrt{3} = 220 \times 1{\cdot}71 = 380$ volts.

The periodicity which has been suggested for use for a standard is fifty periods (~) per second for ordinary lighting and power work, and for special cases where a low periodicity is advisable, such as traction, twenty-five periods per second.

The speeds which are given in the report as generally suitable for direct current motors are :—

B.H.P.	Revolutions per Minute.	B.H.P.	Revolutions per Minute.	B.H.P.	Revolutions per Minute.
¼	1,600	5	1,000	30	750
½	1,400	7½	1,000	40	700
1	1,400	10	900	50	650
2	1,100	15	850	75	550
3	1,100	20	800	100	550

For induction type alternating current motors, where the speed is fixed by the periodicity of the circuit and the number of pairs of poles per phase in the motor, the following are suggested as suitable synchronous speeds. The actual speed will, of course, be the synchronous speed less the slip, which, as shown on page 48, varies from about 7 to 8 per cent. in the small sizes, down to about 2½ per cent.

in the larger. The conditions which affect the slip have already been referred to :—

B.H.P.	Revolutions per Minute.	B.H.P.	Revolutions per Minute.	B.H.P.	Revolutions per Minute.
1	1,500	10	1,500	40	750
2	1,500	10	1,000	50	750
3	1,500	15	1,000	75	600
5	1,500	20	1,000	75	600
7½	1,500	25	750	100	500
7½	1,000	30	750		

The output of a motor is determined by the permissible temperature rise of any part, after a run for a specified time at its normal full load. Since an important source of loss in any motor is the heating of the armature and field coil conductors, the effective output with a given temperature rise depends upon the facilities provided for ventilating the motor and so dissipating this heat. The amount of ventilation allowable depends upon the position in which the motor will be placed and the use to which it will be put. It has therefore become usual for manufacturers to classify their machines and to rate them accordingly. The usual divisions can be best understood by reference to the following standard types of Messrs Electromotors' manufactures :—

In the open type shown in Fig. 6 (page 26), the commutator end of the motor is open, and there is every facility for the passage of cool air through the motor and round the commutator. In some cases the commutator end is protected by perforated metal sheeting, thus retarding the free circulation of cool air but protecting the motor from outside interference. In some machines this protection is extended to the openings at the other end of the motor, while in Fig. 7 (page 26), termed the

"totally enclosed" motor, both ends are thoroughly closed in, and the heat generated in the motor must be dissipated by radiation or convection from the outer casing of the motor. It is to increase the radiating surface that some makers rib the outside of the motor frame.

It is evident that the size of a motor for a given output will vary according to the type chosen, since the ventilating arrangements are so different. This means, that the price of the motor will vary in the same way, the more complete the protection, the higher the price. In practice the same motor carcase is rated differently according to the type. Thus the "D" size of Messrs Electromotors' machines require a base $21\frac{1}{8}$ in. long by 30 in. wide, and the overall height is $27\frac{3}{8}$ in. It is rated at 10 B.H.P. at 1,000 revolutions per minute, or it may be wound if desired for 15 B.H.P. at 1,500 revolutions per minute. The list price in the semi-enclosed pattern is £54, and in the enclosed ventilated type, with perforated coverings at both ends, which does not sensibly affect the output, £55. 10s. If supplied as a totally enclosed machine, the highest recommended output is 6 B.H.P. at 800 revolutions per minute, the price remaining at £55. 10s.

There are places where the presence of dust or other conditions makes the use of totally enclosed motors necessary, but in nearly every case, enclosed ventilated motors serve the purpose, and by their use the capital outlay is kept within reasonable limits.

The outputs given above are obtained with a maximum temperature rise of 75° Fahr. above surrounding atmosphere in the case of open and semi-enclosed machines as shown on Fig. 6, of 85° Fahr. temperature rise in the enclosed ventilated pattern, and of 90° Fahr. with the totally enclosed pattern, Fig. 7, all temperatures being taken after a six hours' run at rated full load, the standard air temperature being taken as 70° Fahr.

Since the safe output of a motor is determined in nearly

all cases by its temperature after a long period of continuous working, it has been generally agreed that one of the best tests to apply to a motor before purchasing, is to run it for a stated time at normal full load output, and determine the temperature rise at different points of the motor. For motors designed for continuous working, a six hours' full load run has been taken as a fair period. It is perhaps unnecessarily long with small motors where the mass of metal is small and the limiting temperature is reached in two or three hours, and not long enough with large machines where the temperature slowly rises for many hours, but if allowance is made for special conditions it gives very useful information, and is a good test of the running properties of the motor, qualities which are quite as important as the electrical.

The length of the test run at rated full load for motors intended for intermittent working, suggested by the Engineering Standards Committee, was one hour, but this has been objected to, and is now being reconsidered. The requirements are so varied that it is difficult to fix a definite period. For crane and hoist motors, which only work for short periods at a time, half an hour's run at rated full load seems ample, and has been adopted as standard by many manufacturers.

There are two ways of measuring the temperature of the coils at the end of the run; the usual one consisting of placing thermometers, covered with wadding to prevent radiation, as close as possible to the coil, thus measuring the temperature at that point, and the more accurate one of taking the electrical resistance of the coil at the commencement and end of the run, and from the difference, calculating the average temperature of the coil. For taking the temperature of the iron cover the thermometer is essential.

The maximum temperature rise allowed in the Engineering Standards report for motors in which ordinary insulating materials are used is 108° Fahr. (60° Cent.) measured by means of the resistance method, or 90° Fahr. (50° Cent.)

for moving coils when the temperature is measured by means of a thermometer. It will be noticed that for ordinary patterns of motors the standard temperature rises allowed by the best makers are below the above maximum figures, 75° Fahr. and 85° Fahr. being generally accepted as the highest which should be adopted, if it is desired to use motors, which will safely stand an overload of 25 per cent. for periods up to one hour at a time. This is not at all an unusual requirement for motors intended for continuous working. If the motors are intended for use in hot climates where the air temperature is higher than the 77° Fahr. (25° Cent.) taken as standard by the Committee, a reduction in the permissible temperature rise of 1° Fahr. should be made for each 1° Fahr. rise in the air temperature, in order that the temperature of the motor when in use shall not in any part exceed 185° Fahr. (85° Cent.).

Some makers are adopting for use as insulating materials, substances which are able to withstand high temperatures without injury. In such cases the permissible maximum temperature may be safely increased, but this should only be allowed after full consideration of all the conditions. There are many, who consider that in the case of induction motors with squirrel cage wound short circuited rotors, where the rotor bars only carry low tension current, that the above mentioned temperature limits are unnecessarily severe, but for all but special cases they appear to be as high as is consistent with safety.

Low cost of maintenance and repairs depends to a large extent upon the rating of the motor being suitable for its maximum, as well as its average work. Its economy in working depends upon its average efficiency.

Efficiency is the name given to the ratio between the useful work done by the motor and the total electrical energy given to the motor, and is usually expressed as a percentage of the useful work done.

There are several methods in which the efficiency of a

motor may be determined, the one usually adopted when the motor is below 15 or 20 B.H.P. being the brake test. This is both direct, and easy to carry out. A Prony or other form of friction brake is fitted up capable of absorbing the full power of the motor. If it is a direct current machine, a reliable ammeter and voltmeter for measuring the energy applied and a tachometer or speed counter complete the apparatus required. In carrying out the test the motor is started, the load applied, and when it is steady simultaneous readings are taken of the ammeter and voltmeter to measure the electrical energy given to the motor, and of the weight on the brake arm, and the speed to determine the brake horse-power given out. The ratio of the two multiplied by 100 gives the percentage efficiency.

The following record of an actual test carried out on a direct current crane motor is typical of good modern practice.

The motor was rated for crane service at 18 B.H.P. to work on a 460 volt circuit. It was run for half an hour steadily at this load, at the end of which time the following temperature rises above the surrounding atmosphere were measured by means of thermometers :—

Commutator - - - -	53° Fahr.
Armature core - - - -	59° Fahr.
Field core - - - -	51·5° Fahr.

The allowable temperature rise under above conditions was 75° Fahr.

The load was kept constant by means of a Prony brake, having an arm 3·11 ft. or 37·32 in. long.

The measurements taken for this test were :—

Speed of motor = 597 revolutions per minute.
Weight on brake = 52·5 lbs.
Current supplied to motor = 36 amperes.
Pressure at motor terminals = 460 volts.
Effective length of brake arm = 3·11 ft.

$$\therefore \text{ B.H.P.} = \frac{2\pi \times \begin{array}{c}\text{length of brake}\\ \text{arm in feet}\end{array} \times \begin{array}{c}\text{revolutions}\\ \text{per minute}\end{array} \times \begin{array}{c}\text{weight on brake arm}\\ \text{in lbs.}\end{array}}{33{,}000}$$

$$= \frac{2 \times 3{\cdot}1417 \times 3{\cdot}11 \times 597 \times 52{\cdot}5}{33{,}000}$$

$$= 18{\cdot}5 \text{ B.H.P.}$$

Electrical input

$$= \frac{36 \text{ amperes} \times 460 \text{ volts}}{746} = 22{\cdot}2 \text{ H.P.}$$

Percentage efficiency at full load

$$= \frac{18{\cdot}5 \times 100}{22{\cdot}2} = 83{\cdot}30 \text{ per cent.}$$

In order to further test the insulation of the armature and field coils, it is usual to apply not less than twice the working pressure for a period of half a minute or a minute between the conductors and the frame, or a higher voltage momentarily. In this case, the pressure applied in the form of alternating current pressure might be 1,500 volts applied for one minute, or 2,000 volts for a moment. This is termed in practice the flashing test.

In the above calculations use has been made of certain relationships between the mechanical and electrical units which it will be well to refer to in further detail. In Chapter I., page 16, it was shown that the relationship —known as Ohm's law—between the volt, the unit of electrical pressure; the ampere, the unit of rate of flow of current; and the ohm, the unit of electrical resistance; might be expressed for direct currents as:—

$$\text{Amperes} = \frac{\text{volts}}{\text{ohms}}.$$

$$\text{Ohms} = \frac{\text{volts}}{\text{amperes}}.$$

$$\text{Volts} = \text{amperes} \times \text{ohms}.$$

The rate of doing work in an electrical circuit is expressed in watts, which may be taken as the product of the amperes

into the electrical pressure, or as the product of the volts into the amperes, thus:—

$$\begin{aligned}\text{Watts} &= \text{volts} \times \text{amperes}\\ &= \text{amperes}^2 \times \text{ohms}\\ &= \frac{\text{volts}^2}{\text{ohms}}\end{aligned}$$

The watt, the unit of rate of doing work in an electrical circuit, is the rate of working when a current of one ampere flows along an electrical circuit, the difference of pressure between whose ends is one volt.

It should be borne in mind that the watt expresses the rate of working, and is equivalent to a unit of power, the work done in an electrical circuit depends upon the rate of working and the time during which that rate was maintained.

In mechanics the rate of doing work is measured by comparison with the movement of a given mass or weight —one pound, through a given distance—one foot, in a given time—one second. It is therefore one foot-pound per second. This is too small for a practical unit, so the horse-power is usually taken.

This is the rate of working when a mass or weight of 550 lbs. is moved through a distance of one foot in one second, or sixty times this amount, or 33,000 lbs. through the same distance in one minute, or of course a correspondingly less weight through a correspondingly longer distance.

The horse-power only expresses rate of working; the work done is determined by the rate of working, and the time during which that rate of working is maintained. The usual practical unit of work done is the horse-power hour, which is one horse-power—rate of working maintained for one hour—time of working.

The relation between electrical and mechanical activity or rate of working can be determined by finding out the work which is done in a given time and comparing results. Very careful determinations have been made of the work

done in an electrical circuit in a given time by measuring the amount of electrical energy converted into heat in a coil of wire, and noting the rise of temperature produced in a given mass or weight of water.

It is found that when work is being done at the rate of one watt, it is equivalent to mechanical work done at the rate of moving 0·7372 lb. through a distance of one foot in one second, or 44·236 lbs. through the same distance in one minute.

The equivalent in watts of 1 H.P. is therefore

$$\frac{33,000}{44 \cdot 236} = 746 \text{ approximately.}$$

The electrical energy flowing in an electrical circuit, or its rate of doing electrical work, may if desired be expressed in horse-power since,

$$\text{Watts} = \text{amperes}^2 \times \text{ohms} = \text{amperes} \times \text{volts.}$$

$$\text{Horse-power} = \frac{\text{amperes}^2 \times \text{ohms}}{746} = \frac{\text{amperes} \times \text{volts}}{746}.$$

Thus in the test referred to above the horse-power supplied to the motor was found out by means of this formula, thus:—

$$\frac{36 \text{ amperes} \times 460 \text{ volts}}{746} = 22 \cdot 2 \text{ H.P.}$$

The electrical work done by the passage of an electrical current through a circuit is represented by the transformation of some of the electrical energy into heat energy. The amount thus transformed depends upon the rate of flow of current and the electrical resistance; and as shown above, varies with the square of the current.

Thus if we have an electrical circuit with a resistance of 2 ohms, the horse-power required to drive a current of 25 amperes through it will be:—

$$\text{Horse-power} = \frac{\text{amperes}^2 \times \text{ohms}}{746} = \frac{25^2 \times 2}{746} = \frac{1250}{746}$$
$$= 1 \cdot 67 \text{ horse-power.}$$

The commercial and legal standard in this country for electrical work done is at present termed the Board of Trade

Unit. It represents the work done in a circuit by 1,000 watts working for one hour or its equivalent. Since 1,000 watts is termed a kilowatt, it is sometimes called a kilowatt-hour. Both these terms are inconvenient, and it is probable that the name Kelvin will soon come into commercial use. This term is, of course, suggested not merely as suitable, but in memory of the great scientist, Lord Kelvin, who did so much to further the science and practice of accurate electrical measurement.

One Board of Trade Unit, therefore, equals

$$\frac{1000}{746} = 1{\cdot}34 \text{ H.P. hours.}$$

The equivalent in foot-pounds of work of a horse-power hour as shown above is

$$33{,}000 \times 60 = 1{,}980{,}000 \text{ ft.-lbs.}$$

The equivalent in foot-pounds of work of a Board of Trade unit is, from the equivalents given above,

$$\frac{1{,}980{,}000 \times 1000}{746} = 2{,}654{,}179 \text{ ft.-lbs.}$$

The usual standard of comparison in this country for heat energy measurement is the British Thermal Unit, which is the name given to the amount of heat required to raise the temperature of 1 lb. of water from 68° Fahr. to 69° Fahr. This is equivalent to 778 ft.-lbs.

The equivalent of 1 H.P. hour in British Thermal Units is therefore

$$\frac{1{,}980{,}000}{778} = 2{,}545 \text{ B.Th.U.}$$

and of one Board of Trade Unit—

$$\frac{2{,}654{,}179}{778} = 3{,}411 \text{ B.Th.U.}$$

With the above formulæ it is easy to determine the normal full load current of any motor at the supply voltage, thus if the working pressure is 460 volts, and we have a motor

which at full load, gives 10 B.H.P. and has an efficiency of 86 per cent., the current required by the motor will be :—

$$\frac{10 \text{ B.H.P.} \times 746 \text{ watts} \times 100}{460 \text{ volts} \times 86} = 18{\cdot}8 \text{ amperes.}$$

It is also possible to calculate the heat efficiency of any installation. Thus in the large works whose weekly cost of working is detailed in Chapter VIII., page 169, we find that the units generated per week amount to 35,100 units and that the total coal used—at the average rate of 5 lbs. of coal per kilowatt-hour or unit—equals say 79 tons per week.

The number of British Thermal Units in 1 lb. of coal varies with the quality between about 12,000 to 14,500; for the purpose of this calculation the medium value of 13,500 B.Th.U. per pound of coal will be taken.

The total energy supplied to the works in the course of one week expressed in British Thermal Units will be :—

$$13{,}500 \times 2{,}240 \times 79 \text{ tons} = 2{,}388{,}960{,}000 \text{ B.Th.U.}$$

Assuming that the whole of the energy is used for driving motors, and that the motors have an average efficiency including losses in the distributing system of 85 per cent., the total brake horse-power hours developed by the 35,100 units generated will be :—

$$\frac{35{,}100 \times 85 \times 1{,}000}{100 \times 746} = 39{,}993 \text{ H.P. hours.}$$

Since the heat equivalent of one H.P. hour is 2,545 B.Th.U., the number of British Thermal Units represented by the motor load will be :—

$$39{,}993 \times 2{,}545 = 101{,}782{,}185 \text{ B.Th.U.}$$

The percentage heat efficiency of the whole system, that is the percentage ratio of the energy represented by the brake horse-power of the motors to the total energy contained in the coal, is :—

$$\frac{101{,}782{,}185 \times 100}{2{,}388{,}960{,}000} = 4{\cdot}26 \text{ per cent.}$$

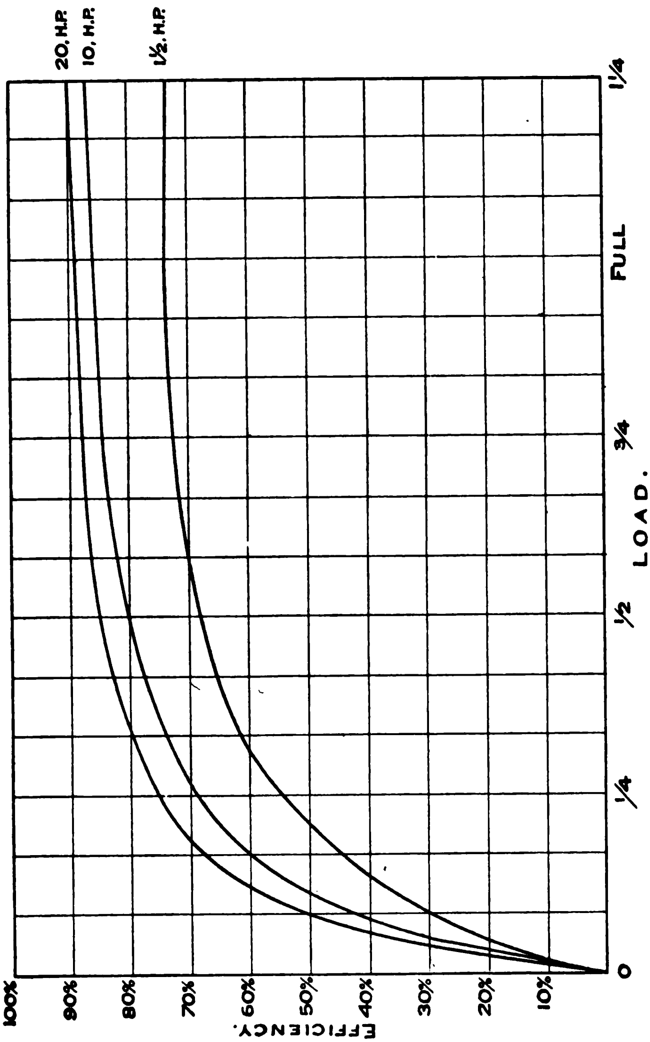

Fig. 47.—Curves showing the Percentage Efficiency of Direct Current Motors of Various Sizes at Different Loads.

This figure shows how low under ordinary working conditions the heat efficiency of even a well-planned power installation really is. Of course on special test runs, when the plant is run on steady full load for a specified time, a much higher efficiency can be got, such as 13½ or even 15 per cent. for steam and 17 to 20 per cent. for gas plants, but even here there is great room for improvement.

The percentage efficiencies which may be expected at varying loads in direct current motors made by first-class firms, such as Electromotors Ltd., are shown on Fig. 47, where—

> The bottom curve is for a motor rated to give 1½ B.H.P. at 1,600 revolutions per minute.
>
> The middle curve is for a motor rated to give 10 B.H.P. at 1,000 revolutions per minute.
>
> The top curve is for a motor rated to give 20 B.H.P. at 875 revolutions per minute.

It will be seen that the losses in small motors are considerably more than in larger sizes, and that unless the individual motors in an installation are of fairly large size, or by using a number of small motors other savings may be effected, the extra losses in the motors themselves will prove a serious matter, quite apart from the interest and depreciation charges on the larger capital outlay required for the small motors.

In Fig. 48 the efficiency of a 15 B.H.P. three-phase 500 volt 50 ~ induction type motor, as made by the Electric Construction Co., is shown. It will be seen that the efficiency itself is about the same as for a direct current motor under similar conditions, but that underneath the efficiency curve there is another curve which shows the power factor of the motor under varying loads. At full load this is 86 per cent., at half load 79 per cent., and at quarter load 61½ per cent. As explained on page 38 this indicates the increase in the current due to the "impedance" of the circuit, which increase is not represented by actual work.

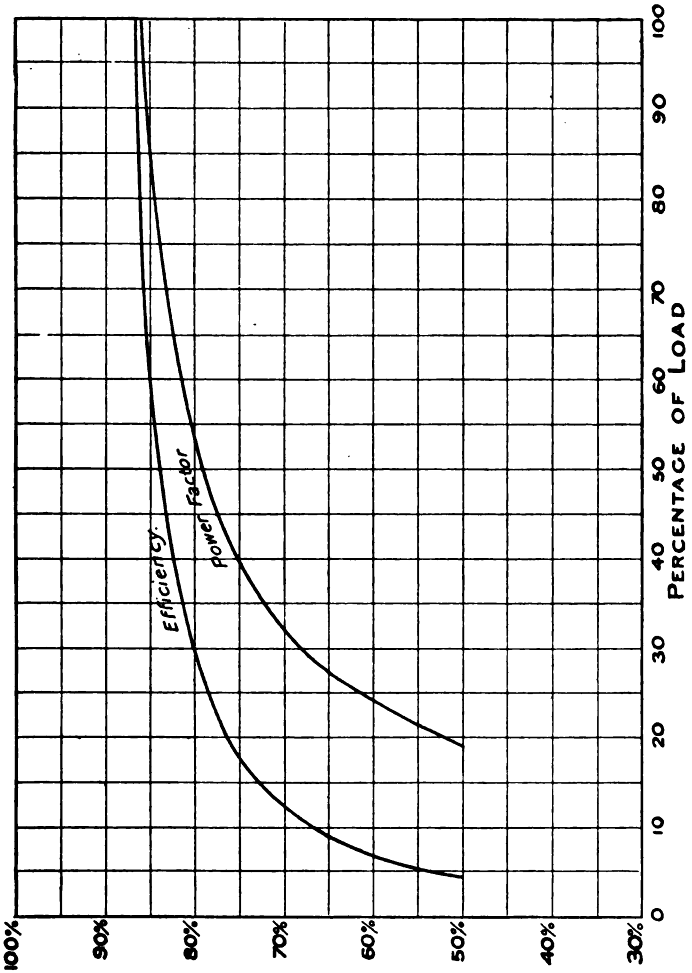

Fig. 48.—Curve showing the Efficiency and Power Factor at Various Loads of 15 B.H.P., 500 volt 50 ~ Three-Phase Induction Motor.

This affects the current required to drive the motor though it does not increase the power it gives out.

The current actually flowing in the circuit will be greater than it would be if the power factor were unity by the following percentages :—

$$\text{Full load} = \frac{14 \times 100}{86} = 16{\cdot}3 \text{ per cent.}$$

$$\text{Half load} = \frac{21 \times 100}{79} = 26{\cdot}6 \text{ per cent.}$$

$$\text{Quarter load} = \frac{38{\cdot}5 \times 100}{61{\cdot}5} = 62{\cdot}6 \text{ per cent.}$$

These increased currents have to be provided for in determining the sizes of the distributing cables, or else the losses will be considerably reduced, and the efficiency of the installation correspondingly lessened.

It is very necessary when testing induction motors to have in circuit a reliable wattmeter to measure the real energy supplied to the circuit. The product of the voltmeter and ammeter readings only gives the apparent energy being supplied to the circuit, the wattmeter gives the real energy, and the ratio between the two is the power factor.

SECTION II.—THE PROVISION OF ELECTRIC ENERGY.

CHAPTER V.

THE COST OF ENERGY AS AFFECTED BY CONDITIONS OF WORKING.

Effect of Varying Conditions of Use upon Cost of Electrical Energy—Variable Charges for Public Electricity Supply—Meaning of Terms "Plant Load Factor" and "Load Factor"—Average and Maximum Loads—Cost of Working a Gas Engine Installation under Different Conditions—Effect on Cost per Unit—Central Station Load Factors—The Maximum Demand System of Charging for Electrical Energy—"Diversity Factor"—How it Affects Cost of Supply from Central Stations or Size of Generating Plant in Private Installations.

ONE of the most difficult tasks in considering the question of electric driving, is to fully appreciate the extent of the effect on cost, of the conditions under which electric energy is generated. It is this fact, which permits so many statements—true in themselves as to cost of power—to be made in such a way that the hearer gets a wrong impression as to their meaning in his particular case.

The same causes affect the cost of working gas, oil, or steam engines, so that, to obtain definite comparisons as to the relative cost of using different forms of power, it is essential that the conditions under which the power is to be used should be the same.

The standard unit of electrical energy—that is electrical work done—whether called a Board of Trade unit, a Kilowatt-hour, or by its latest name, the Kelvin, is the same, and represents the same amount of work done, whatever the conditions may be under which the energy is used. But while the work value of a kelvin is unalterable, the cost

value constantly varies and sometimes gives rise to some curious results.

Thus in domestic installations, two meters are often placed on the same house service, one to measure the energy supplied to the lamps used for lighting, and the other for the energy supplying the radiator lamps used primarily for heating. There is no difference in the energy used for the two circuits, in fact it is supplied to the house along the same wires, yet very different rates are charged, the lighting units being often two or three times as dear as the heating units.

A little inquiry will also show that in many districts the charge made for lighting units is not a definite sum, but some figure which varies between two extremes according to the maximum number of lamps which may have been alight at any one time. In a few cases, such as with some classes of consumers at Norwich, there is a low fixed charge per unit made for units actually used, plus a fixed percentage on the rateable value of the house.

A study of the prices charged by all the electricity supply undertakings in the country show that about 40 per cent. have a fixed price, or, as it is termed, a flat rate for lighting units, another 40 per cent. offer an option between a fixed and a variable rate, while the remainder give no choice, but insist upon the customer accepting a variable rate of charge.

The reason for these apparent complications lies, of course, in the fact that the cost of producing and distributing an electrical unit depends upon the conditions under which it is generated and used. It is not possible here to deal fully with the varying conditions, but some explanation of the principles of power generation will enable a fair estimate to be formed of the cost of electrical energy used for a particular purpose under stated conditions.

In the first place, suppose that a small gas engine drives a dynamo which is only used for charging a battery of accumulators. All the energy required for the lamps or

motors is taken from the battery, which is of such a size that it is emptied each night, and it takes the dynamo eight hours during the daytime, working at full load, to charge it.

The gas engine and dynamo work at their best efficiency and maximum output all the time, only one attendant is required, and the number of units supplied to the battery is the same each day, since the battery is working under similar conditions, that is, it is completely discharged each night, and fully charged each day. Consequently, the cost of each unit taken from the battery is practically the same, whether the battery is discharged slowly or quickly, since although used under different, the energy was produced under similar conditions.

The terms generally used to express the conditions under which electrical energy is generated are "plant load factor" and "load factor." The "plant load factor" is the ratio of the electrical units actually produced by an electrical generator or group of generators to the number which would have been produced had the generator or group of generators worked continuously at full load for the same period. It is usually expressed as a percentage.

Thus in the above case the "plant load factor" is 100 per cent. since the dynamo works at full load all the time. The higher the plant load factor, the more favourable for economy are the conditions under which the plant is working. Such plant load factors as 100 per cent. are only commercially obtainable when accumulators of large capacity, relative to the work to be done, are installed; for ordinary working the combination of dynamo with battery is too expensive, and the charges for repairs and renewals, together with the interest and depreciation allowances, would far outweigh the gain due to the higher efficiency of the plant. It will, however, be noted in this case that the size of dynamo and gas engine is determined by the rate at which the battery is charged, and not by the maximum load on the battery, a difference which permits of a considerable reduc-

tion in the size and cost of the generating plant, and this goes some way towards balancing the cost of the battery.

While the "plant load factor" indicates the conditions under which a single generator or group of generators is working, the term "load factor" has a wider and more general application. It is used to express the ratio as a percentage between the units actually generated or used in an installation or distributing system, to the number of units

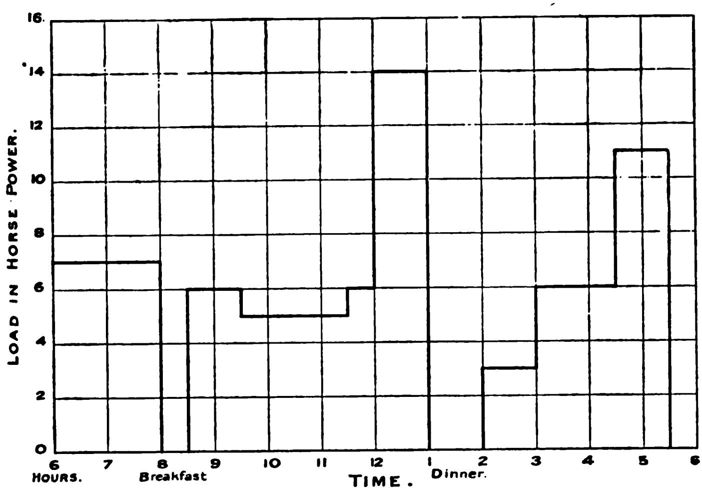

Fig. 49.—Diagram illustrating varying Demand for Power in Factory during Working Day.

which would have been generated or used had the maximum load been maintained for the whole period to which the term is applied. For instance, it is said that the load factor of a certain electricity supply undertaking in a small town with a purely lighting load is $12\frac{1}{2}$ per cent. for a given year. This means that the units actually sold during that year are one-eighth of those represented by the maximum load in kilowatts during the year, multiplied by 8,760, the total number of hours in the year.

The term is equally applicable to a small installation, and may be used to cover any period of time; the only point to note is that in making comparisons the same period is taken for both cases.

Fig. 49 shows how the term may be used in connection with the daily work in connection with a motor installation in a factory where the load varies between 3 and 14 B.H.P. In practice the changes in load will be more frequent and more abrupt, the figures and times taken are chosen simply to illustrate the principle on which the load factor is calculated. The diagram shows how a load curve is made; it should really be termed a time load curve.

It works out as follows:—

6.0 A.M.	to	8.0 A.M.	= 7 B.H.P. × 2 hrs. =	14 B.H.P. hrs.
8.0	,,	8.30 ,,	= Breakfast interval.	
8.30	,,	9.30 ,,	= 6 B.H.P. × 1 hr. =	6 ,,
9.30	,,	11.30 ,,	= 5 B.H.P. × 2 hrs. =	10 ,,
11.30	,,	12.0 noon	= 6 B.H.P. × ½ hr. =	3 ,,
12.0 noon	to	1.0 P.M.	= 14 B.H.P. × 1 hr. =	14 ,,
1.0 P.M.	to	2.0 ,,	= Dinner interval.	
2.0	,,	3.0 ,,	= 3 B.H.P. × 1 hr. =	3 ,,
3.0	,,	4.30 ,,	= 6 B.H.P. × 1½ hrs. =	9 ,,
4.30	,,	5.30 ,,	= 11 B.H.P. × 1 hr. =	11 ,,
			Total =	70 B.H.P. hrs.

The maximum load was 14 B.H.P., and the time of work ten hours, so that the maximum possible brake horse-power hours were:—

$$14 \times 10 = 140 \text{ B.H.P. hours,}$$

and the percentage daily load factor is:—

$$= \frac{70 \times 100}{140} = 50 \text{ per cent.}$$

In large stations the load is either automatically recorded on a recording wattmeter, and the actual units generated or sold found by integrating the space enclosed by the curve,

or readings of output are taken at the switchboard every quarter or half hour, and entered in the log book. This gives the maximum load; the units actually generated or sold are found by the difference in the station meter readings.

In order to see the effect which alterations in the load factor has upon the cost of producing electrical energy, it will be well to take a special case, and, using the same generating plant, find out the cost per unit with varying weekly outputs.

For this purpose a small factory with a self-contained generating plant will suffice. The generating plant consists of a gas engine driving a dynamo through belting, and the price of gas is 2s. per 1,000 cub. ft. The aggregate load of the motors and shafting is 45 B.H.P., and, assuming an average efficiency, the full load requirements will be 40 KW.

The cost of installing such a plant varies with the type of plant chosen, but an average figure for a gas engine capable of developing up to 65 B.H.P., a 40 KW. direct current dynamo, all foundations, the necessary switchboard, belting, dynamo connections, water vessels, pipe connections, and erection ready for working would be £560.

The following assumptions are made in the various estimates:—

The gas consumptions per KW. hour are taken as:—

26 cub. ft.	per KW.	hour at	full load.
30	,,	,,	three-quarter load.
36	,,	,,	half load.
55	,,	,,	quarter load.

These figures correspond to:—

17½ cub. ft.	per B.H.P.	hour at	full load.
19½	,,	,,	three-quarter load.
23	,,	,,	half load.
34	,,	,,	quarter load.

These consumptions would be considerably improved on in test runs in makers' works under specially favourable conditions, but they may be accepted as near the average figures obtained in ordinary working.

The working hours per week are taken as fifty-six.

The repairs are calculated throughout on percentages of the capital outlay corresponding with results actually obtained in places where ordinary care has been exercised. This is a factor on which the personal element of the interest of the attendant in his daily work has an important influence.

An allowance at the rate of 10 per cent. per annum on the whole capital outlay is made in all cases to cover the items of interest on capital, and depreciation. This should enter into all considerations of cost of working. The rate allowed by different manufacturers varies, and while many manufacturers would allow 12 to 12½ per cent., 10 per cent. may be assumed an average fair figure on which to base comparative estimates.

No allowance is made for proportion of rent, rates, and taxes, as this is a very variable amount, and is the same in all the cases under immediate consideration.

Four cases will be taken :—

First.—Assuming the ideal condition of the plant working at full output all the time, that is, with a plant load factor of 100 per cent.

Second.—With the plant working on an average at three-quarter load, that is, with a plant load factor of 75 per cent.

Third.—With an average load of half full load, or a plant load factor of 50 per cent.

Fourth.—With an average of quarter load or a plant load factor of 25 per cent.

First Case.—The conditions of working are:—

Full load of plant - - - -	= 40 KW.
Average load - - - - -	= 40 KW.
Working hours per week - -	= 56 hours.
Units generated per week	= 40 × 56 = 2,240 units.
Plant load factor - - - -	= 100 per cent.

The weekly cost of working is:—

	Cost.			Pence. per Unit.
	£	s.	d.	
GAS, 2,240 units at 26 cub. ft. per unit = 2,240 × 26 = 58,240 cub. ft. at 2s. per 1,000 cub. ft. - -	5	16	6	0·62
OIL, 1 gal. for ten hours' running, say 6 gals. at 1s. 8d. per gal. -	0	10	0	0·06
WATER, say 2½ gals. of fresh water per unit = 2·5 × 2,240 = 5,600 gals. at 6d. per 1,000 gals. - - -	0	2	10	0·01
WASTE, STORES, AND SUNDRIES, say - - - - - - -	0	5	0	0·03
LABOUR, say one man at 22s. -	1	2	0	0·12
ALLOWANCE FOR OCCASIONAL SUPERVISION, say - - -	0	2	6	0·01
ALLOWANCE FOR REPAIRS, say one week at rate of 3½ per cent. per annum on £560 - - -	0	7	6	0·04
ALLOWANCE FOR INTEREST AND DEPRECIATION CHARGES, say one week at rate of 10 per cent. per annum on £560 - - -	1	1	6	0·12
Total weekly cost - -	9	7	10	1·01

Second Case.—The conditions are:—

Full load of plant - - - -	= 40 KW.
Average load - - - - -	= 30 KW.
Working hours per week - -	= 56 hours.
Units generated per week	= 30 × 56 = 1,680 units.
Plant load factor - - - - -	= 75 per cent.

The weekly cost of working is:—

	Cost.			Pence per Unit.
	£	s.	d.	
GAS, 1,680 units at 30 cub. ft. per unit = 1,680 × 30 = 50,400 cub. ft. at 2s. per 1,000 cub. ft. - -	5	0	10	0·72
OIL, say 1 gal. for eleven hours' running, say 5 gals. at 1s. 8d. per gal. - - - - - -	0	8	4	0·06
WATER, say $2\frac{1}{2}$ gals. of fresh water per unit = 2·5 × 1,680 = 4,200 gals. at 6d. per 1,000 gals. - - -	0	2	3	0·02
WASTE, STORES, AND SUNDRIES, say	0	4	6	0·03
LABOUR, one man at 22s. - -	1	2	0	0·15
ALLOWANCE FOR OCCASIONAL SUPERVISION, say - - -	0	2	6	0·02
ALLOWANCE FOR REPAIRS, say one week at rate of $3\frac{1}{4}$ per cent. per annum on £560 - - - -	0	7	0	0·05
ALLOWANCE FOR INTEREST AND DEPRECIATION CHARGES, say one week at rate of 10 per cent. per annum on £560 - - -	1	1	6	0·15
Total weekly cost - -	8	8	11	1·20

Third Case.—The conditions are:—

Full load of plant - - - -	= 40 KW.
Average load - - - - -	= 20 KW.
Working hours per week - -	= 56 hours.
Units generated per week	= 20 × 56 = 1,120 units.
Plant load factor - - - -	= 50 per cent.

The weekly cost of working is:—

	Cost.			Pence per Unit.
	£	s.	d.	
GAS, 1,120 units at 36 cub. ft. per unit = 1,120 × 36 = 40,320 cub. ft. at 2s. per 1,000 cub. ft. - -	4	0	8	0·86
OIL, say 1 gal. for thirteen hours' running, say 4 gals. at 1s. 8d. per gal. - - - - -	0	6	8	0·07
WATER say, 2½ gals. of fresh water per unit = 2·5 × 1,120 = 2,800 gals. at 6d. per 1,000 gals. - - -	0	1	5	0·02
WASTE, STORES, AND SUNDRIES, say	0	4	0	0·04
LABOUR, one man at 22s. - -	1	2	0	0·23
ALLOWANCE FOR OCCASIONAL SUPERVISION, say - - -	0	2	6	0·02
ALLOWANCE FOR REPAIRS, say one week at rate of 3 per cent. per annum on £560 - - -	0	6	5	0·07
ALLOWANCE FOR INTEREST AND DEPRECIATION CHARGES, say one week at rate of 10 per cent. per annum on £560 - - -	1	1	6	0·24
Total weekly cost - -	7	5	2	1·55

Fourth Case.—The conditions are:—

Full load of plant - - -	= 40 KW.
Average load - - -	= 10 KW.
Working hours per week -	= 56 hours.
Units generated per week -	= 10 × 56 = 560 units.
Plant load factor - - -	= 25 per cent.

The weekly cost of working is:—

	Cost.			Pence per Unit.
	£	s.	d.	
GAS, 560 units at 55 cub. ft. per unit = 560 × 55 = 30,800 cub. ft. at 2s. per 1,000 cub. ft. - -	3	1	7	1·33
OIL, say 1 gal. for sixteen hours' running, say 3½ gals. at 1s. 8d. per gal. - - - - -	0	5	10	0·12
WATER, say 2½ gals. of fresh water per unit = 2·5 × 560 = 1,400 gals. at 6d. per 1,000 gals. - - -	0	0	8	0·01
WASTE, STORES, AND SUNDRIES, say - - - - - - -	0	3	6	0·08
LABOUR, one man at 22s. - -	1	2	0	0·47
ALLOWANCE FOR OCCASIONAL SUPERVISION, say - - -	0	2	6	0·05
ALLOWANCE FOR REPAIRS at rate of 2¾ per cent. per annum on £560 - - - - - -	0	5	11	0·12
ALLOWANCE FOR INTEREST AND DEPRECIATION CHARGES, say one week at rate of 10 per cent. per annum on £560 - - -	1	1	6	0·46
Total weekly cost - -	6	3	6	2·64

From the above instances it will be seen how the plant load factor affects the cost per unit generated.

The figures are:—

100 per cent.	plant load factor,	cost	per unit	generated	1·01d.
75	,,	,,	,,	,,	1·20d.
50	,,	,,	,,	,,	1·55d.
25	,,	,,	,,	,,	2·64d.

These results are shown on Fig. 50, where the percentage plant load factors are plotted as abscissæ, and the cost per unit generated as ordinates. The costs per unit at inter-

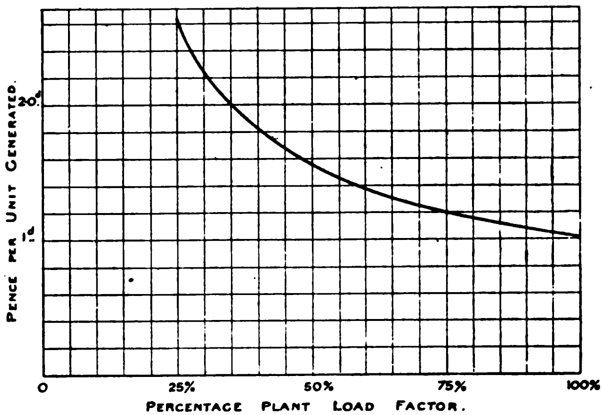

Fig. 50.—Curve showing Effect of Load Factor on Cost per Unit of Electric Energy.

mediate plant load factors can be taken from the curves. These figures can only be approximate, as the load would not in practice be steady, but varying from time to time, consequently, though the average load may be a definite percentage of full load, it does not follow that the average gas consumption per brake horse-power hour is the corresponding figure for that particular fraction of full load.

The above example, which is typical of ordinary practice, shows how the efficiency of the plant is affected by the

average load, and the influence the permanent charges, which in this case comprise the cost of labour, repairs, and interest and depreciation on the capital outlay, have on the result. It points out, too, that efficiency may be purchased at too high a cost in capital outlay, since the interest and depreciation allowances on the extra capital outlay may more than counterbalance the savings effected by the alteration.

If the above were required to work at a fairly high load factor the whole of the twenty-four hours, the cost per unit generated could be appreciably reduced. It would be necessary to employ more labour, either two men working twelve hours a day each, or three men working eight hours each, and the cost of repairs would be increased owing to the extra wear and tear, but the allowance for interest and depreciation would be the same, and being spread over a larger number of units the amount per unit would be correspondingly less.

In central station work the load factor of the system rather than the plant load factor of the individual generating sets is the important feature, since with proper care on the part of the station attendants the plant load factor of the running sets can be kept high, although the general load factor of the system may be low.

The load factor of a suburban district supplying principally private residences is rarely higher than 11 or 12 per cent.; with a good proportion of power customers, and a tramway load, the load factor may go up to 25 or 30 per cent., but it rarely rises higher in public supply undertakings.

The average load factor for 1906-07 of 282 undertakings tabulated by the *Electrical Times*, was only 17·22 per cent., no one station distributing energy direct, reaching 30 per cent. It is said that the Newcastle-on-Tyne Electric Supply Co. Ltd., who supply so many large power users in the Tyne district, have an annual load factor approaching 40 per cent., but at present this is an exceptional case. There is, therefore, a

wide margin in every undertaking for improvements to be made before the load factor even approaches the ideal 100 per cent., when the costs of production would be a minimum. One of the power companies, the Yorkshire Electric Power Co., is endeavouring to fill in this gap by selling energy to a chemical manufacturing company at very low rates during the hours of light load, the supply being cut off at the times when the ordinary load makes heavy demands on the station.

The low load factor of a purely lighting load explains why electrical energy generated under these conditions must be comparatively dear, and justifies the high charges which are sometimes made for units used for this purpose.

The aim of every central station engineer is to improve his load factor, and to do this he must increase his sales in every direction, and endeavour to obtain as many different classes of customers as possible, so that their periods of heavy load may not coincide. By so doing, he will reduce his cost of production, and increase his load factor. It is with this object that the long hour consumer who burns a small number of lamps long periods each day, has been encouraged by such special methods of charging as the maximum demand system. Here, each consumer has, in addition to his meter, a maximum demand indicator which tells the maximum current since the last reading. In making out the bill the total number of units as shown by the meter are taken. Part of the number, represented by the maximum load as registered by the indicator, multiplied by either one or one and a half, are charged at the high rate and the remaining units at the lower rate. Those charged at this high rate represent the maximum demand during the quarter maintained for either one or one and a half hours per day, according to the basis of charge adopted.

For instance, if a consumer has used 450 units in a quarter, and his maximum demand is 2½ KW., equivalent to forty 16 candle-power lamps on at one time, his bill

would be, if the two rates were 7d. per unit for one hour per day of maximum demand for the high priced and 1½d. per unit for the low priced units:—

2½ units × 91 days × 1 hour per day =	
228 units at 7d. per unit - - -	£6 13 0
450 − 228 = 222 units at 1½d. per unit -	1 7 9
	£8 0 9

or an average of 4·29d. per unit, the load factor of this particular customer for the quarter, or 91 days, being:—

$$\frac{450 \times 100}{2{\cdot}5 \text{ units} \times 91 \text{ days} \times 24 \text{ hours}} = \frac{45{,}000}{5{,}460} = 8{\cdot}24 \text{ per cent.}$$

If the customer had used the same number of units, but his maximum number of lamps alight at any one time had been twenty 16 candle-power lamps representing 1¼ units, his bill would have been made out thus:—

1·25 units × 91 days × 1 hour per day =	
114 units at 7d. per unit - - -	£3 6 6
450 − 114 = 336 units at 1½d. per unit -	2 2 0
	£5 8 6

or an average charge of 2·89d. per unit, the load factor in this case being:—

$$\frac{450 \times 100}{1{\cdot}25 \text{ units} \times 91 \text{ days} \times 24 \text{ hours}} = \frac{45{,}000}{2{,}730} = 16{\cdot}48 \text{ per cent.}$$

This method of charging, popularly associated with the name of Mr Arthur Wright, who introduced it some years ago at Brighton, is theoretically correct in regulating the average price per unit according to the maximum demand on the station of the particular customer, that is according to his load factor. Owing largely to the difficulty of getting customers to understand why they may be called on to pay different average prices for the same number of units of

energy used for the same purpose, it has never proved really popular, and the tendency to-day is towards flat rates of charge for units sold for ordinary lighting purposes, graduated scales being reserved for large power users and energy required for special purposes.

A good deal of attention has been given during the past two or three years to another consideration which has a very real influence upon the price at which electric energy may be profitably sold by the supply undertaking. It is the effect of supplying energy to a number of consumers, the character of whose demands differ, and whose periods of maximum load occur at different times of the day or night.

This is termed the "diversity factor," and may be explained as the ratio of the sum of the maximum demands of all the customers concerned divided by the actual observed maximum load of those customers.

For instance, take the case of twelve tradesmen who each have electric motors to a total of 12 H.P. installed on their premises. Their ordinary work needs 5 B.H.P., but each occasionally wants all his motors to work at full load. With some, this full load period comes on in the morning, with some in the afternoon, with others in the evening; in no cases do the periods of full load of the various tradesmen clash.

The maximum demand of each customer is 12 B.H.P., or a total of $12 \times 12 = 144$ B.H.P. The maximum demand upon the station at any one time is :—

Eleven customers having motors averaging a load of 5 B.H.P. each $= 11 \times 5$ -	55 B.H.P.
One customer having motors loaded up to	12 ,,
	67 B.H.P.

The diversity factor in this particular case is

$$= \frac{144 \text{ B.H.P. (sum of maximum demands)}}{67 \text{ B.H.P. (actual maximum demand)}} = 2{\cdot}15.$$

This ratio of actual maximum demand to the possible maximum demand is an all-important one in relation to the question of cheap supply from a central station, as well as in determining the size of an independent generating plant for a large installation.

If we take an extreme case where there is one large motor in a works and an independent generating plant, the generating plant must be capable of running the motor at full load, and the diversity factor will be 1.

In the case mentioned earlier in this chapter, where motors to an aggregate of 45 B.H.P. were installed, if they were required to work at full load simultaneously, the diversity factor would be 1, and the generating plant must be able to supply the total horse-power installed, although the average load may be very much less.

In industrial works the periods of full load on the various motors rarely coincide, and in fixing prices of energy if the energy is purchased, or the size of the generating plant—which determines the capital outlay—if the energy is generated on the premises, the diversity factor of that particular installation must be taken into account. Since this is difficult to determine in works where mechanical methods of driving are employed, the data obtained by comparing the estimated total horse-power of the various machines with the indicated horse-power of the engine should be checked by as many comparisons with similar works driven by electric power as possible.

Take a case of a works where the following eight motors were installed :—

3 of 20 B.H.P.	- - - - - =	60 B.H.P.
3 of 10 ,,	- - - - - =	30 ,,
1 of 7 ,,	- - - - - =	7 ,,
1 of 30 ,,	- - - - - =	30 ,,
Total	- - - =	127 B.H.P.

These motors were used for different purposes, and the maximum demand they made on the generating plant was 40 B.H.P.

The diversity factor was therefore :—

$$\frac{127 \text{ B.H.P.}}{40 \text{ B.H.P.}} = 3{\cdot}17.$$

It would therefore be sufficient to have a generating plant capable of developing 40 B.H.P., or one-third of the total B.H.P. of the different motors installed in the works. The first cost of such a plant would be considerably lower than that of a plant capable of supplying all the motors at full load at the same time, and working at full load it would work under better conditions as to economy than the larger plant. The proportion of interest and depreciation charges per unit would be reduced owing to the lower capital outlay, so that the total working costs would be considerably less. There would, however, be the risk, that if all the motors were for any reason required to work at full load at the same time for any lengthy period, the generating plant would not be equal to the demand for energy, and would be found too small for its work.

A central station averages out this risk by seeking to supply customers of all classes, and it is found that the more varied the character of the demand, the higher the diversity factor of the system.

Even on a load like the London County Council Tramway system, the diversity factor is 1¼, on large supply systems with both power and lighting connections the figure rises to 2 or 2½, and in some places it is 3 or 3¼. These figures compare the total actual maximum demands of each consumer with the observed maximum demand, so are independent of the total B.H.P. of the motors installed in the various premises. On a large system where there are a number of different classes of consumers, and the station is well designed with suitable spare plant and a large over-

load capacity of the generating units in use, there is practically no risk of the supply of energy at any moment falling below the demand, and this is one of the great advantages of a large supply system as compared with the small independent plant.

In the large power schemes which have during the past few years been brought forward for the supply of electric energy in bulk at cheap rates over the metropolitan area, it has been estimated that the capital cost of a large generating station would not exceed £12 per KW. installed. This is, of course, a very low figure compared with the costs of independent plants, but before delivery of the energy to the customer there are distribution losses and the effect of the proportion of the capital cost of the distribution system to consider.

Owing, however, to the influence of the diversity factor, this one KW. of plant installed at the station is capable of supplying more than 1 KW. of the consumer's maximum demand, the increase depending upon the diversity factor. In some of the schemes referred to a diversity factor of 1·66 has been assumed, so that the proportion of the station capital charges to be considered when estimating possible prices to be charged is not £12 per KW. of consumer's demand, but $\frac{£12}{\text{diversity factor}} = \frac{£12}{1{\cdot}66} = £7{\cdot}2$ per KW.

If the diversity factor is taken at a higher figure, the amount will be still further reduced. This reduction in the capital cost, which must be allocated, makes a very considerable difference in the standing charges, which must be charged against each customer, and is one cause of the low charges which it is possible for a power company or large supply undertaking to make for electric energy, and yet for them to make a profit on the sale.

CHAPTER VI.

THE QUESTION FOR THE SMALL POWER USER.

Needs of Small Power User—Electric Motors *v.* Gas Engines—Comparison of Cost for Small Installation—Effect on Cost, of Continuous and Intermittent Working of Gas Engine—Shafting Losses *v.* Motor Losses—Effect of Dividing the Load on Cost—Estimate of Relative Costs of Working of Different Systems—Advantages of Electric Motors.

THERE are in every town a large number of people who need power for the efficient carrying on of their business. The individual needs of each of these power users may be small, but the question of the cost of this power to them is of equal and perhaps greater importance than it is to the larger manufacturer with his correspondingly increased demand.

Speaking generally, the term small power user may be given to the person who requires less than 12 H.P. to be installed, and who uses his motors at intermittent periods. Small printing establishments, bakeries, laundries, butchers, hairdressers, small engineering works such as cycle and motor repair shops, and innumerable other industries, come under this category, and their importance as a class of customers has been fully recognised by many electricity supply undertakings, as well as by the makers of gas and oil engines. The diversity factor of such consumers is very high. It was recently stated that in Glasgow over 75 per cent., or 1,600, of the power consumers connected to the mains, needed less than 5 B.H.P. at any one time, and these

small motors in the aggregate formed over 25 per cent. of the total load. In many districts low rates, and what is perhaps more important still, rental systems for the hire of motors, have resulted in the greater number of these small power users adopting electric driving. There are still, however, very many cases in which considerable savings could be effected by electric driving were it not for the fact that gas or oil engines already installed makes the owner reluctant to make a change.

It will perhaps, be well to take several cases, typical of ordinary conditions, and see, first, how on the question of cost the two systems of electrical and mechanical drive compare, and afterwards to refer to other factors which it is equally important to bear in mind when considering the matter.

There are several towns in which gas can be obtained for power purposes at 2s. per 1,000 cubic feet, and electric energy for motors at 1d. per unit. As these are practically minimum rates, it will be well to base any comparative figures on them. In such cases, the choice for the small user lies principally between the gas engine supplied with town's gas, and the electric motor.

Take first, the case of a person—say a small printer or baker—who only wants about 2 B.H.P. at intermittent periods, totalling in all about thirty hours per week. With the gas engine he needs a total of 30 feet of shafting; an electric motor can be placed in a more convenient position, and 20 feet of shafting is sufficient.

The electric motor can be started or stopped at any time by merely closing the main switch, and moving the handle of the starting switch; it takes several minutes of careful attention to start the gas engine. This means, that in many cases the gas engine is kept at work the whole of the time in order to save delay when the power is required. It is only in exceptional cases, that the engine can be started each time it is wanted. The figure of 2 B.H.P. includes

the loss in the shafting. In the case of the electric motor with the shorter length of shafting, the B.H.P. required would not exceed, say, $1\frac{3}{4}$ B.H.P. The overload capacity of both gas engine and motor will be sufficient to meet any temporary overload on the driven machines.

The outlay in each case will be approximately :—

ELECTRIC MOTOR—

One 2 B.H.P. electric motor complete with starting resistance and main switch and fuse - - - - - - -	£30	0	0
ALLOWANCE for fixing and wiring for motor. No special foundations necessary -	4	0	0
ALLOWANCE for supplying and fixing 20 ft. of shafting with necessary supports, pulleys, and belts - - - - -	9	0	0
Total -	£43	0	0

GAS ENGINE—

One 2 B.H.P. gas engine complete with water vessel, accessories, and necessary pipe connections to gas and water - - - - - - -	£36	0	0
ALLOWANCE for fixing and foundations -	9	0	0
ALLOWANCE for supplying and fixing 30 ft. of shafting with necessary supports, pulleys, and belts - - - - -	15	0	0
Total -	£60	0	0

The approximate weekly cost of working will be :—

ELECTRIC MOTOR.

Taking the efficiency of the motor at 82 per cent., the number of units to be purchased each week will be :—

$$\frac{1{\cdot}75 \times 100 \times 746 \times 30}{82 \times 1{,}000} = 47{\cdot}7, \text{ say 48 units per week.}$$

The cost is :—

	£	s.	d.
ENERGY, 48 units at 1d. per unit - -	£0	4	0
OIL and ATTENDANCE, including that required for shafting, say - - -	0	1	0
ALLOWANCE FOR REPAIRS, say one week at rate of 3 per cent. per annum on £43. 0s. 0d. - - - - - -	0	0	6
ALLOWANCE FOR INTEREST AND DEPRECIATION ON CAPITAL OUTLAY, say one week at rate of 10 per cent. per annum on £43. 0s. 0d. - - - .	0	1	8
Total -	£0	7	2

GAS ENGINE.

Taking first, the case where the gas engine is stopped when the power is not being used, we find that the engine works at practically full load for thirty hours per week, when the gas consumption may be taken as 22 cub. ft. of gas per B.H.P. hour.

The cost is :—

	£	s.	d.
GAS, 2 B.H.P. for thirty hours = 60 B.H.P. hours = 60 × 22 = 1,320 cub. ft. of gas at 2s. per 1,000 cub. ft. - -	£0	2	7½
OIL, 1 gal. for twenty hours' working, say 1½ gals. at 1s. 8d. per gal. - -	0	2	6
WATER, say 600 gals. at 6d. per 1,000 gals.	0	0	3½
LABOUR, say one quarter of man's time = one quarter of £1. 2s. - - - -	0	5	6
ALLOWANCE FOR REPAIRS, say one week at rate of 3 per cent. per annum on £60. 0s. 0d. - - - - - -	0	0	8
ALLOWANCE FOR INTEREST AND DEPRECIATION ON CAPITAL OUTLAY, say one week at rate of 10 per cent. per annum on £60. 0s. 0d. - - - - -	0	2	1
Total -	£0	13	8

If the gas engine is run all the time the cost of attention might be slightly reduced, since the number of starts would be less, but the amount of gas used would be increased, since the engine would be simply running round for the additional twenty-six hours. The gas consumption for these conditions for the extra twenty-six idle hours would not be less than 38 cub. ft. per hour.

The weekly cost would therefore now be, assuming that the power required to run the shafting alone is 1 B.H.P. :—

	£	s.	d.
GAS, 60 B.H.P. hours at 22 cub. ft. per B.H.P. hour = 1,320 cub. ft. 26 B.H.P. hours at 38 cub. ft. per B.H.P. hour = 988 = 2,308 cub. ft. at 2s. per 1,000 cub. ft. - - - -	£0	4	8
OIL, 1 gal. for twenty-five hours' working, say 2·5 gals. at 1s. 8d. per gal. - -	0	4	2
WATER, say 1,000 gals. at 6d. per 1,000 gals.	0	0	6
LABOUR, say one man one hour per day = six hours at 22s. per week, say -	0	2	1
ALLOWANCE FOR REPAIRS, say, one week at rate of 3½ per cent. per annum on £60. 0s. 0d. - - - - - -	0	0	10
ALLOWANCE FOR INTEREST AND DEPRECIATION ON CAPITAL OUTLAY, say one week at rate of 10 per cent. per annum on £60. 0s. 0d. - - -	0	2	1
Total -	£0	14	4

The approximate relative costs of gas and electricity, with gas at 2s. per 1,000 cub. ft. and electric energy at 1d. per unit, when working under the above conditions, would be :—

	£	s.	d.	
Electricity - - - - - -	£0	7	2	per week.
Gas engine (working intermittently)	0	13	8	,,
Gas engine (working continuously)	0	14	4	,,

The total cost in electric driving, excluding the amount paid for electric energy, is—

7s. 2d. less 4s. = 3s. 2d.

Deducting this sum from the total cost of working by means of the gas engine working intermittently, we have—

13s. 8d. less 3s. 2d. = 10s. 6d.,

as the sum which might have been paid for electric energy without the total cost exceeding that of gas under above conditions.

As there were 48 units of electric energy used, the highest permissible cost per unit would be—

$$\frac{10\text{s. } 6\text{d.}}{48} = \frac{126\text{d.}}{48} = 2{\cdot}63\text{d. per unit.}$$

Similarly, with the gas engine working continuously, we have as the permissible amount to spend on electric energy—

14s. 4d. less 3s. 2d. = 11s. 2d.

$$= \frac{11\text{s. } 2\text{d.}}{48} = \frac{134\text{d.}}{48} = 2{\cdot}79\text{d. per unit.}$$

There are other considerations to be borne in mind, which have a very important bearing on the relative advantages for these conditions of the two systems of working.

For instance, the space occupied by the gas engine is far greater than that required by the motor, which may, if thought advisable, be bolted to the ceiling, and the starting switch placed on the wall in any convenient position. The foundations for the gas engine must be substantial, and to avoid nuisance the exhaust must be carried clear of the building.

The noise inseparable from the working of a small gas engine, is considerably more than the slight hum of the

motor, while the dislocation to business in the case of a break-down is far less with the electric motor, than the gas engine.

In the case of small users, whose requirements are of an intermittent character, there is no doubt that it is better to purchase electric energy at any reasonable figure and instal an electric motor than go to the larger expense of buying and fixing a gas engine. The savings are so considerable, without making any allowance for the contingent advantages just referred to, that in many cases it will pay to incur the loss of disposing of an existing gas engine, and installing an electric motor.

A small engineering works may be taken as another typical case. Here there are a number of lathes and other machine tools requiring in all say 10 B.H.P. to drive them. The choice here, is to connect them together by means of shafting and belting, and drive them as one unit, or to group the machines in three or four lines, and drive each line separately. If a gas engine is used, the first plan must of necessity be adopted. With electric motors, it is easy to subdivide the power, arrange the machines to be driven in groups with the minimum of shafting, and by placing the motor in the centres of the lengths of shafting reduce the required size of the shafts.

Sometimes all the machines would be working at full load at the same time, but under ordinary conditions the load would not average more than 5 B.H.P. at the machines for the full time the plant was running, say the usual fifty-six hour working week.

It may fairly be assumed, that with the gas engine drive, 90 ft. of shafting would be required, but that with the machines arranged, in say four groups, the length of shafting can be reduced to a total of 60 ft. The average size of the shafting in the case of all the power being transmitted from one point will be $2\frac{1}{2}$ in. diameter, and in the case of the four motors 2 in. diameter.

The comparison can be made between driving the works—

(*A*) From a gas engine installed at one point;

(*B*) From an electric motor installed in place of the gas engine, no other change being made in the driving arrangements;

(*C*) From four electric motors placed at suitable points, each driving a length of shafting.

In the case of the single power unit, when all the power has to be transmitted along the shafting from one point, experience teaches us that the loss may be anything between 25 and 50 per cent. of the maximum power transmitted, or say 2½ B.H.P.

This means that the gas engine or single motor must be capable of giving 12½ B.H.P. as normal full load, while the average load will be 5 B.H.P. plus the shafting loss, say 7½ B.H.P. at the engine or motor.

In the case of the four short lengths of smaller shafting used with the four motors, it will be sufficient to allow 2 B.H.P. for the shafting loss, so that each motor must be capable of giving $2\frac{1}{2}+\frac{1}{2}=3$ B.H.P. as its normal full load.

The approximate capital cost in the three cases would be:—

A. Gas Engine Drive:—

One 13 B.H.P. gas engine, 220 revolutions with flywheel, water vessel, pipe connections and necessary accessories, delivered on site - - - - -	£90	0	0
Foundations for above engine and cost of fixing and connecting to gas and water	18	0	0
90 ft. of 2½ in. steel shafting, with all necessary hangers and bearings, pulleys and belting, delivered and fixed, say -	54	0	0
Total	£162	0	0

B. Electric Drive with Single Motor:—

One 13 B.H.P. motor, speed about 900 revolutions per minute, complete with starting resistance, main switch, and fuse, and all necessary accessories -	£70	0	0
Allowance for fixing motor, the necessary wiring in steel conduit and all connections, say - - - - - -	8	10	0
90 ft. of 2½ in. steel shafting with all necessary hangers, bearings, pulleys, and belting, delivered and fixed, say -	54	0	0
Total	£132	10	0

C. Electric Drive with Four Motors:—

Four 3 B.H.P. motors, about 1,200 revolutions per minute, complete with starting resistance and main switch and fuse at, say, £32 each - -	£128	0	0
Allowance for fixing motors, the necessary wiring in steel conduit and all connections, say - - - - - -	22	0	0
60 ft. of 2 in. shafting, with all necessary hangers, bearings, pulleys, and belting, delivered and fixed, say - - - -	30	0	0
Total	£180	0	0

The relative costs of installation would therefore be:—

Gas engine - - - - - -	£162	0	0
Electric drive (single motor) - -	132	10	0
Electric drive (four motors) - -	180	0	0

Working Costs.

A. Gas Engine Drive.

The average load to be provided for at the engine will be

the 5 B.H.P. required at the machine plus the $2\frac{1}{2}$ B.H.P. lost in the shafting, or a total of $7\frac{1}{2}$ B.H.P., the engine working at practically 60 per cent. of its normal full load for fifty-six hours per week.

The gas consumption per B.H.P. hour under these conditions will be about 25 cub. ft. per B.H.P. hour.

The number of B.H.P. hours will be:—

$$7{\cdot}5 \times 56 = 420 \text{ B.H.P. hours per week.}$$

The engine will require, say, a gallon of oil for each twenty hours of working, and the shafting bearings about 1 gallon per week, or a total of, say, 4 gallons per week.

The weekly cost of working will be:—

	£	s.	d.
GAS, 420 B.H.P. hours at 25 cub. ft. per B.H.P. hour = 420 × 25 = 10,500 cub. ft., at 2s. per 1,000 cub. ft. - -	£1	1	0
OIL, 4 gals. at 1s. 8d. per gal. - - -	0	6	8
WATER, say 3,000 gals. at 6d. per 1,000 gals.	0	1	6
LABOUR, say one man to attend to engine and lubricate shafting, say one-third time at £1. 2s. per week - -	0	7	4
ALLOWANCE FOR REPAIRS, say one week at rate of 3 per cent. per annum on £162. 0s. 0d. - - - - - -	0	1	9
ALLOWANCE FOR INTEREST AND DEPRECIATION ON CAPITAL OUTLAY, say one week at rate of 10 per cent. per annum on £162. 0s. 0d. - - -	0	5	9
Total -	£2	4	0

B. ELECTRIC DRIVE WITH ONE MOTOR.

The load to be provided for will be the same as for the gas engine since the shafting losses are the same; the motor will be loaded on an average to 60 per cent. of its full load output, and the efficiency may be taken as about 85 per

cent. Under these conditions the number of units of energy required to be purchased will be:—

$$\frac{7 \cdot 5 \times 56 \times 100 \times 746}{85 \times 1{,}000} = 368 \cdot 6 \text{ units, say 369 units per week.}$$

The weekly cost of working will be:—

ENERGY, 369 units at 1d. per unit - -	£1	10	9
OIL FOR MOTOR, say ¼ gal. + SHAFTING, 1 gal. = 1¼ gals. at 1s. 8d. per gal. -	0	2	1
PROPORTION ATTENDANCE, OILING SHAFTING, EXAMINING MOTOR, &c., say one hour per day = six hours at 22s. per week - - - - - -	0	2	4
ALLOWANCE FOR REPAIRS, say one week at rate of 3 per cent. per annum on £132. 10s. 0d. - - - - -	0	1	6
ALLOWANCE FOR INTEREST AND DEPRECIATION ON CAPITAL OUTLAY, say one week at rate of 10 per cent. per annum on £132. 10s. 0d. - -	0	5	1
Total -	£2	1	9

C. ELECTRIC DRIVE WITH FOUR MOTORS.

The average load at the machine is 5 B.H.P. for the whole of the fifty-six working hours, and the shafting losses are assumed to be 2 B.H.P., so that the load on the motors is 7 B.H.P., spread over the whole period of working of fifty-six hours. The motors are working with an average load of about 60 per cent. of normal full load, with an average efficiency of, say, 80 per cent.

Under these conditions the number of units to be purchased each week will be:—

$$\frac{7 \times 56 \times 100 \times 746}{80 \times 100} = 365 \cdot 5, \text{ say 366 units per week.}$$

The weekly cost of working will be :—

ENERGY, 366 units at 1d. per unit - -	£1	10	6
OIL FOR MOTORS AND SHAFTING, say ¾ gal. at 1s. 8d. per gal. - - - - -	0	1	3
PROPORTION ATTENDANCE, OILING SHAFTING AND EXAMINING MOTORS, say four hours at 22s. per week -	0	1	7
ALLOWANCE FOR REPAIRS, say one week at rate of 3 per cent. per annum on £180	0	1	11
ALLOWANCE FOR INTEREST AND DEPRECIATION CHARGES ON CAPITAL OUTLAY, say one week at rate of 10 per cent. per annum on £180. 0s. 0d. -	0	6	11
Total -	£2	2	2

While the price paid for electric energy is only 1d. per unit, the average total cost per unit, including proportion of attendance, repairs, and interest and depreciation charges, is:—

In the case of the single large motor

$$\frac{£2.\ 1s.\ 9d.}{369} = 1{\cdot}35d. \text{ per unit,}$$

and with the four motors

$$\frac{£2.\ 2s.\ 2d.}{366} = 1{\cdot}38d. \text{ per unit.}$$

The relative costs of working are therefore :—

A. Gas Engine—

£2. 4s. 0d., or an average of $\frac{£2.\ 4s.\ 0d.}{56} =$ 9·43d. per hour.

B. Electric Drive with Single Motor—

£2. 1s. 9d., or an average of $\frac{£2.\ 1s.\ 9d.}{56} =$ 8·95d. per hour.

C. Electric Drive with Four Motors—

£2. 2s. 2d., or an average of $\frac{£2.\ 2s.\ 2d.}{56} =$ 9·00d. per hour.

It will be seen from the above tables that so far as direct cost goes there is not much difference between the three methods; that the gas engine drive is slightly the dearest, the other two methods being for these conditions practically the same.

If, in some departments, overtime has to be worked, the advantage of the subdivided electric drive is shown at once.

Assuming, that in one department with a load of 1 B.H.P. at the machines, it is necessary to work late for two hours per night, the extra cost would be, neglecting any further sum for interest and depreciation charges which are already allowed for:—

A. Gas Engine Drive:—

	£	s.	d.
Gas, say 2 B.H.P. per night for machine $+ 2\frac{1}{2} \times 2 = 5$ B.H.P. for shafting losses $= 7$ B.H.P. hours per night five nights per week $= 35$ B.H.P. hours at, say 35 cub. ft. of gas per B.H.P. hour $= 35 \times 35 = 1{,}225$ cub. ft. at 2s. per 1,000 cub. ft. - - - - - -	£0	2	5
Oil, say ½ gal. at 1s. 8d. per gal. - -	0	0	10
Water, say 500 gals. at 6d. per 1,000 gals.	0	0	3
Attendance, one man ten hours at overtime rates = ten hours at 22s. + 25 per cent. - - - - - - -	0	4	11
Allowance for Repairs for extra hours of running, say $\frac{\text{1s. 9d.} \times 10}{56}$, say -	0	0	4
Total -	£0	8	9

Or an average of $\frac{\text{8s. 9d.}}{10} = 10{\cdot}5\text{d.}$ per hour.

B. ELECTRIC DRIVE WITH SINGLE MOTOR :—

ENERGY, say 1 B.H.P. at machines + $2\frac{1}{2}$ B.H.P. to drive shafting = 3·5 B.H.P. for two hours per night for five nights during week = $3 \cdot 5 \times 2 \times 5 = 35$ B.H.P. hours per week. Motor efficiency, say 72 per cent. Units $= \frac{35 \times 100 \times 746}{72 \times 1{,}000} = 36 \cdot 2$ units, say 37 units at 1d. per unit - -	£0	3	1
OIL, say, for shafting, $\frac{1}{4}$ gal. at 1s. 8d. per gal. - - - - - - -	0	0	5
ATTENDANCE, Foreman in charge to turn off switch when work finished - -		...	
EXTRA ALLOWANCE FOR REPAIRS, say $\frac{\text{1s. 6d.} \times 10}{56}$ - - - - - -	0	0	3
Total -	£0	3	9

Or an average of $\frac{\text{3s. 9d.}}{10} = 4 \cdot 5$d. per hour.

C. ELECTRIC DRIVE WITH FOUR MOTORS :—

ENERGY, only one of the four motors will be required ∴ Load = 1 B.H.P. at machine + $\frac{1}{2}$ B.H.P. for that part of shafting = $1\frac{1}{2}$ B.H.P. for two hours per night five nights during week $= 1 \cdot 5 \times 2 \times 5 = 15$ B.H.P. hours. Motor efficiency, say 75 per cent. Units $= \frac{15 \times 100 \times 746}{75 \times 1{,}000} = 14 \cdot 9$ units, say 15 units at 1d. per unit - -	£0	1	3
OIL for shafting, say $\frac{1}{8}$ gal. at 1s. 8d. per gal. - - - - - - -	0	0	3
Carried forward - -	£0	1	6

Brought forward - -	£0 1 6
ATTENDANCE, Foreman in charge to turn off switch when work finished - -	...
EXTRA ALLOWANCE FOR REPAIRS, say $\frac{1s.\ 11d. \times 10}{56}$, say - - - - -	0 0 3
Total -	£0 1 9

Or an average of $\frac{1s.\ 9d.}{10} = 2{\cdot}1d.$ per hour.

It is when working at light loads, that the advantages of the electric motor, with its possibility of reducing shafting losses, and avoiding the large gas consumption per B.H.P. hour, are most marked.

The comparative costs of the ten hours' extra working of one section of the works is therefore :—

A. Gas Engine Drive -	8s. 9d.	or 10·5d. per hour.
B. Electric Drive with Single Motor - -	3s. 9d.	„ 4·5d. „
C. Electric Drive with Four Motors - -	1s. 9d.	„ 2·1d. „

In the above comparison no allowance has been made for other advantages than the actual cost of installing and working. The motors occupy far less floor space than the gas engine, are quieter in working, and give a freer hand in arranging the machines. Since they need only be placed in groups, the convenience of the work to be done can be studied to a far greater extent than if the position of all the machines were governed by their proximity to a single source of power, or length of shafting.

The electric motor is also less liable to break down. It is a rare thing for a public supply to be interrupted, and should any defect develop in one of the motors, it is an easy matter to replace the motor, stopping only the section of the shafting which it drives, while, if anything happens to

the gas engine or large motor the whole of the machinery is stopped till the repair is effected. The full benefit of this freedom from anxiety from stoppage of work is only fully realised when a break-down occurs during a specially busy period. At such times the question of even a small increase in the cost of electric driving, if that were the case, is felt to be far outweighed by the certainty of the supply and the reliability of the motors.

In this case the full benefits of the electric drive have not been taken advantage of. The machines have been assumed to be divided into four groups, and shafting has been allowed for each group. Greater efficiency apart from first cost, would have been obtained had separate motors been attached to each tool and intermediate shafting entirely dispensed with. In the equipment of large engineering shops, separate motors for each tool are often advantageous, but in a case like the present, the proportion of the interest and depreciation charges on the extra outlay would more than counterbalance the saving on the power bill.

It would be possible to work out in detail a large number of cases, but they would all go to prove, that, in the case of small power users, that is, where the average power required is below 6 or 8 B.H.P., electric power at any price below 1½d. per unit is preferable to gas engines, using gas bought at 2s. 6d. per 1,000 cub. ft., and that as the power required decreases in amount, or becomes more intermittent as to the period during which it is used, the advantages of the electric drive become more pronounced. If what may be termed the collateral advantages, such as saving of space, freedom from worry, and general convenience, are taken into account, the allowable price for electric driving will be correspondingly increased.

CHAPTER VII.

INDEPENDENT GENERATING PLANTS—OIL AND GAS ENGINE PLANTS.

The Manufacturer's Real Work—Choice between Purchase of Energy and Independent Generating Plants—Typical Works' Installations—Coal-Gas Engine Plant—Oil Engine Plant—Suction Gas Engine Plant—Conditions of Economical Working of Suction Gas Producers—Working Costs of Oil and Suction Gas Plants—Pressure Producer Gas Plants—Large Works' Installation—Cost of Working with Pressure Producer Plant—Recent Improvements in Pressure Producers.

THERE are several reasons which cause manufacturers and works' managers to consider favourably the installation of separate generating plants on their own premises. One of these, is the natural feeling that it is well to concentrate as much as possible under their own control, all processes connected with their special manufactures; another is the thought, that by so doing they are increasing their own independence; and a third is the promises which are held out to them of the low cost at which they can generate energy themselves, compared with that at which it is offered to them by outside authorities.

The first of these reasons is largely based on a misconception of the true function of a manufacturer. It is now becoming general practice for a manufacturer to carry out on his own premises, only those processes which he can do better and cheaper than others, and to purchase as his raw material not merely the rough metal usually associated with that term, but also, all partly manufactured goods, which other specialists can produce better than he can

himself. He is therefore, able to concentrate his attention on the work he can do best, and thus employ his capital to the best advantage. On this ground, there is much to be said against locking up in electrical generating plant a large sum of money, if it is possible to purchase electric energy at a reasonable rate from an outside source. The money thus sunk could be invested in a far more profitable manner in extending the works, or improving the plant. As the manufacturer confines his activities to those channels in which he is a specialist, he is more and more likely to succeed.

The second reason has only to be clearly stated to refute itself. Modern conditions make all so interdependent upon others that the provision of a separate electrical generating plant, if driven by a gas engine, only moves the dependent stage one step back, namely, from the central station engineer to the gas engineer, and if other prime movers are employed, to those engaged in their manufacture and maintenance.

The third reason needs careful examination. Recent improvements in all classes of machinery have so reduced the cost of power, that it has become a question of condition of working rather than anything else, as to what system is best to adopt in any particular case, or whether electric energy should be purchased from an outside source.

The would-be purchaser of electrical generating plant has a wide choice. As soon as he ventilates his wishes he is waited on by a number of zealous representatives of manufacturing firms, who offer him steam plant, oil engine plant, or gas engines, supplied either by town's gas, or producer gas made in either suction or pressure gas producers, and all urge him to adopt the best and most economical plant made, namely, their own. A number of carefully worded statements as to costs of working are produced, and it is often a difficult task to decide whether any of the plants offered are really suitable for the required purpose.

Classifying the various methods, it is found that for large outputs and requirements, the choice lies practically between steam and pressure producer plants, while for small outputs, oil engines, town gas engine plants, and suction gas engine plants each have special advantages to urge, and disadvantages to minimise.

The gas engine supplied with town's gas is more of a rival to the electric motor for driving the works machinery, than a claimant for consideration as a prime mover for the works dynamo. It has many good points in its favour. Its mechanical design is good, and its calorific efficiency high, as even in ordinary sizes of 15 or 20 B.H.P. output they often only require $17\frac{1}{2}$ to 20 cub. ft. of ordinary town gas per B.H.P. hour, or about 26 to 29 cub. ft. per kilowatt hour working at full load. This means about 20 per cent. to 23 per cent. heat efficiency, and compares very favourably with steam plant. It must, however, be remembered that the amount of gas required for the engine is not in any sense directly proportional to the output, as at light loads the amount of gas required per B.H.P. rapidly increases, so that the average amount with a varying load may easily be half as much again per B.H.P. hour as the figure given above, or if the engine valves are not in good order, considerably more.

In comparing the relative costs of town gas, suction gas, oil, and steam for a small generating plant, it will be convenient to take the conditions assumed in Chapter V. when considering the effect of load factor on the cost of producing electric energy.

Here motors to an aggregate of 45 B.H.P. capacity were installed in a factory, representing an approximate load, when all running, of 40 KW. at the generating plant, and the costs of working a town gas supplied gas engine plant at four different load factors were considered. For our present purpose only one of these plant load factors need be taken, and perhaps the best course will be to assume that the

generating plant works at an average of half load throughout the fifty-six hours of a working week, or has a plant load factor of 50 per cent.

A gas engine of the size required for this work would run at about 160 revolutions per minute, and would be fitted with an outside bearing and a heavy fly-wheel to minimise the cyclic variation in speed caused by the fact that in the single cylinder gas engine working on the Otto cycle there is only one impulse every two revolutions.

The engine requires substantial foundations, and also pipe connections from the gas supply as well as for the exhaust to atmosphere, and for connecting the water-cooling tanks to the water supply, and the engines to the drains. The dynamo would be belt-driven and run at about 800 revolutions per minute, and the switchboard would have fitted on it the necessary main switches and fuses, the circuit switches and fuses, and a voltmeter and ammeter for indicating the load on the dynamo. It would also be advisable to include an electricity energy meter, so that the total power used each week can readily be ascertained.

This plant would need a floor space of about 8 ft. 6 in. by 24 ft., and, as already stated, would cost about £560 to instal. Working for fifty-six hours per week at an average plant load factor of 50 per cent., that is, half load with ordinary town gas, the number of units generated per week would be (as shown on page 114, Chapter V.) 1,120 units, and the cost of working, say, £7. 5s. 2d. per week, or an average of 1·55d. per unit generated.

This figure assumes average working conditions and an intelligent man in charge of the plant. It should be possible to slightly reduce the gas consumption, as well as the allowances for oil, stores, and repairs, while any improvement in the plant load factor is reflected in the reduced cost per unit generated, as shown in Fig. 50, page 116. It is important to see that gas engines are periodically cleaned if good average results of working are to be obtained.

Oil engines are now made for this output which have proved thoroughly reliable in actual work. They are, however, more expensive for equal outputs than ordinary gas engines, and require more attention to keep the working parts thoroughly clean. They are useful in places where town gas is not obtainable, and where suction gas is objected to, and with oil at present prices, they compare favourably as regards costs of working with other prime movers. They are often used for isolated country house installations, where coal-gas is not available for supplying an ordinary gas engine.

For outputs up to 6 or 8 KW., oil engines of high speed vertical type, with two or three cylinders, are made suitable for direct coupling to dynamos mounted on the same bedplates, and these plants will often be found very useful. They are very compact, can, if necessary, be easily moved from place to place, and are, of course, quite independent of any gas supply or special gas generating apparatus.

For large outputs the Diesel type of oil engine, which has been introduced into this country from the Continent, has in several cases been successfully employed for driving dynamos supplying tramway systems. They use little oil for fuel, and though the amount of oil required for lubricating is in some cases high, the total cost of working may, under ordinary conditions, be kept low, especially if the plant is kept fully loaded. They are, however, complicated in design, and at the present time their first cost in small units is very high.

The approximate cost of an oil engine plant consisting of two 30 B.H.P. oil engines, each driving through belting a 20 KW. dynamo, together with the necessary accessories and water vessels, switchboard, and connections, would be about £800. As two sets are in this case allowed in order to minimise the inconvenience to the supply when repairs or cleaning are being carried on, it will be possible to work the plant at a higher plant load factor than if a single set

were used, though the other conditions of working remain the same.

The oil consumption per B.H.P. hour at full load under test conditions would probably not exceed 1 pint of oil per KW. hour, or under working conditions say 1·3 pint of oil per KW. hour, and with care at three-quarter load the oil consumption per unit generated should not exceed 1·75 pints.

WORKING COSTS.

The conditions of working are:—

Full load of plant - -	=40 KW.
Number of units and size -	=Two 20 KW. sets.
Average load - - -	=20 KW.
Working hours per week -	=56.
Units generated per week -	$=20 \times 56 = 1{,}120$ units.
Plant load factor - - -	=say 75 per cent.

The weekly cost of working is:—

	Cost.			Pence per Unit.
	£	s.	d.	
OIL, 1,120 units at average of $1\frac{3}{4}$ pints per unit $=\frac{1{,}120 \times 1{\cdot}75}{8}$ $=245$ gals. at $8\frac{1}{4}$ lbs. per gal. $=\frac{245 \times 8{\cdot}25}{2{,}240}=\cdot 9$ ton of Russian oil at, say, 45s. per gal. - -	2	0	6	0·44
LUBRICATING OIL, say 1 gal. for ten hours' working per engine, say 12 gals. at 1s. 8d. per gal. -	1	0	0	0·20
WATER, say 4 gals. of fresh water per unit $=1{,}120 \times 4 = 4{,}480$ gals. at 6d. per 1,000 gals. - -	0	2	3	0·02
WASTE, STORES, AND SUNDRIES, say	0	7	0	0·07
Carried forward - -	3	9	9	0·73

The weekly cost of working—*continued.*

	Cost.			Pence per Unit.
	£	s.	d.	
Brought forward - -	3	9	9	0·73
LABOUR, one man at 22s. - -	1	2	0	0·23
ALLOWANCE FOR OCCASIONAL SUPERVISION - - - -	0	5	0	0·05
ALLOWANCE FOR REPAIRS, say one week at rate of 4 per cent. per annum on £800. 0s. 0d. - . . -	0	12	4	0·13
ALLOWANCE FOR INTEREST AND DEPRECIATION CHARGES ON CAPITAL OUTLAY, say one week at rate of 10 per cent. per annum on £800. 0s. 0d. - - -	1	10	9	0·33
Total weekly cost - -	6	19	10	1·47

The next class of internally fired engines are supplied with what is known as producer gas. This gas is made by passing a mixture of steam and air over incandescent carbon, usually in the form of heated anthracite. It has about one-quarter the calorific value of coal-gas, but is found in practice to be very suitable for gas engine work. The name of Mr J. E. Dowson is closely associated with the introduction of producer gas plants in this country, and what are termed pressure producers have been made by his firm for many years. In fact, in many quarters this gas is commonly known as Dowson gas.

In Dowson producers anthracite coal is used, and the slight pressure needed in the apparatus is obtained by forcing a jet of steam into the producer, thus producing a strong draught of mixed air and steam. This steam is usually obtained from a separately fired boiler, though, in

many cases, a saving in fuel can be effected by making use of the heat contained in the gases, when they leave the producer, to generate the necessary steam. With these pressure producers a small gasholder is provided to equalise the pressure of the gas entering the engine, since the supply of gas by the producer is continuous, and the requirement of the gas engine intermittent, one cylinder charge only being required for every two revolutions of the engine.

Within the past few years a modification of this apparatus, termed the suction gas producer, has come largely into use, in which the gas is made as required for use, by the mixed air and steam being drawn over the heated anthracite by the suction of the gas engine itself, and so dispensing with the need for any gasholder. Such producers are convenient and very efficient if worked at or near full load output.

Their general type is shown in Fig. 51, which represents a standard form of suction gas producer made by the Dowson Economic Gas and Power Co. Ltd. The generator, which is shown on the left of the illustration, is, in its lower part, lined with firebrick, and filled above the grate with small pieces of anthracite. The hopper at the top of the generator has a double door to prevent escape of the poisonous gases produced while the generator is working. A mixing chamber for air and steam is provided round the generator. Air passes through this chamber on its way to the generator, and is mixed with steam produced by the vaporisation of the water, which is sprinkled from the perforated water pipes carried round the mixing chamber as shown in the illustration.

The mixed air and steam pass under the grate and through the fuel, when chemical actions take place between the heated carbon of the anthracite fuel and the mixed air and steam, the final result of which is the formation of the mixture of gases known as producer gas. This passes away from the generator, as shown by the arrows in the diagram,

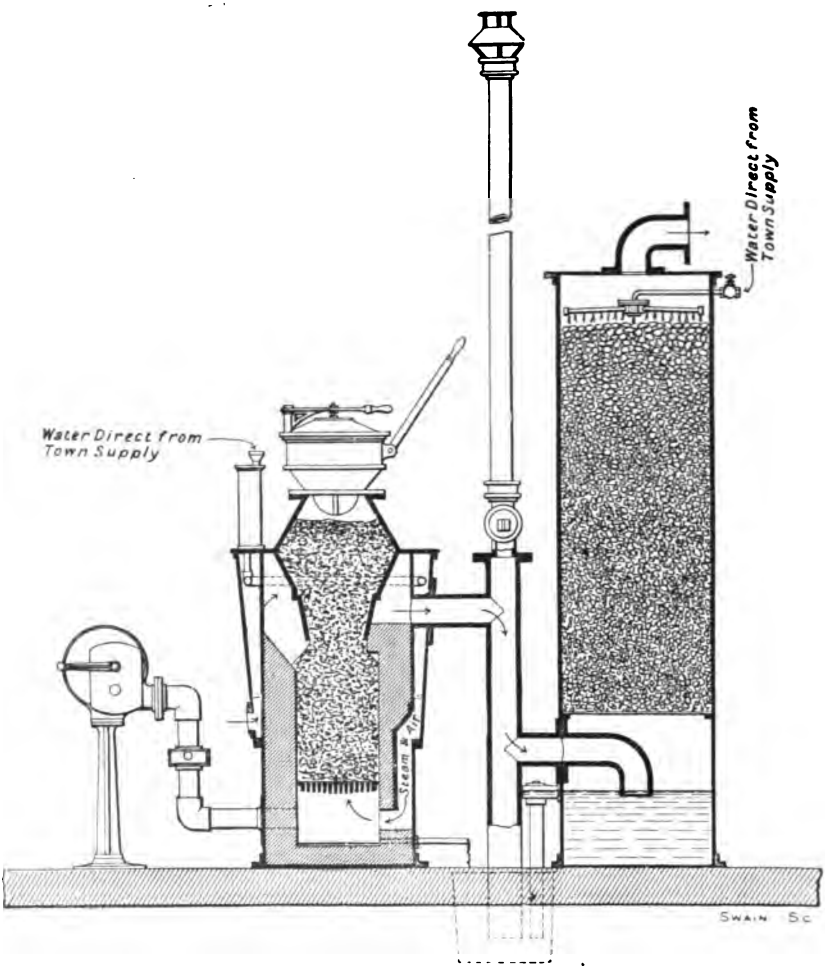

Fig. 51.—Diagram of "Dowson" Suction Gas Producer Plant.

into the bottom of the second vessel, which is known as the coke scrubber. This is filled with small pieces of coke kept cool by the passage of water supplied by the sprinkler at the top.

In passing through the scrubber the gas is cooled and to a small extent cleaned.

From the scrubber it passes direct to the gas engine. The pipe shown between the generator and scrubber is a bye-pass to the atmosphere which is kept open when starting, but after work has been commenced, the connecting valve is closed, and all the gas made passes through the scrubber. The hand blower fan is used to produce a draught sufficient to thoroughly incandesce the mass of anthracite when starting. During the time the producer is at work, the heat given off by the various chemical actions taking place is sufficient to keep up the temperature of the mass of fuel.

The special feature of this type of plant is that the gas is made as required, and no storage is required. The name, suction producer, has been given them, because as soon as the engine slows down or stops, the flow of gas through the apparatus is either retarded or stopped too, and only sufficient new gas is made to make up for the quantity used. There is no outward pressure from the producer tending to force the poisonous producer gas into the air, since the tendency is for the air to leak into the generator, and this is a very valuable practical feature.

These producers only require a small floor space; they should, of course, be placed outside the main building. A 100 H.P. plant can be got into 15 ft. × 11 ft. floor space.

It is not necessary here to follow the various chemical actions which go on in the generator. The entering gases consist principally of oxygen, nitrogen, and steam. In contact with the heated carbon, the steam is dissociated into hydrogen and oxygen, the oxygen—both that present in the

admitted air, and that obtained from the dissociated steam —combines with the carbon to form carbonic acid gas, the greater part of which is, in presence of the glowing fuel, decomposed with the production of carbonic oxide gas.

Both hydrogen and carbonic oxide gas are valuable gases for use in gas engines, the nitrogen and what free carbonic acid there may be left, acting simply as diluting agents. It is necessary to mix air with the producer gas on admission to the gas engine cylinder in order to obtain an explosive mixture. The products of combustion are, of course, steam and carbonic acid gas, which with the nitrogen—partly from the admitted air, and partly that present in the producer gas—must be exhausted into the atmosphere at a point quite clear of the workshop.

It is well to remember that while carbonic acid gas is dangerous to life when present in excess because of its depressing effect, carbonic oxide gas is an active poison acting directly on the blood. Great care must therefore be taken to prevent, either during the starting or working period, any escape of gas into the room or workshop, and means for dealing with accidental cases of carbonic oxide poisoning should always be at hand.

The composition of the gases made by different plants vary within fairly wide limits, and even the gas from the same producer is affected as to heat value and composition by the conditions of load.

Thus in a 40 B.H.P. suction type producer working with gas coke instead of anthracite, Mr J. E. Dowson found the gas produced, when the engine was working at full and light loads respectively, varied as follows :—

	Per Cent. by Volume.	
	Full Load.	Light Load.
Carbonic oxide gas, CO -	27·65	22·40
Hydrogen, H_2 - -	9·85	7·00
Carbonic acid gas, CO_2 -	3·80	4·90
Oxygen, O_2 - - -	0·30	0·50
Nitrogen, N_2 - - -	58·40	65·20
	100·00	100·00
Heat value of gas in B.Th.U. per cub. ft. - -	128·90	101·00

There is a considerable difference, too, between the heat value of the gases made in suction plants, as compared with pressure plants. Thus the following figures, also given by Mr Dowson, show the relative values of the above 40 B.H.P. suction plant and a similar sized pressure gas plant, both using anthracite and both having the advantage of a hot start :—

	Per Cent. by Volume.	
	Suction Producer.	Pressure Producer.
Carbonic oxide gas, CO -	20·13	23·80
Hydrogen, H_2 - -	15·64	19·80
Carbonic acid gas, CO_2 -	6·09	6·30
Oxygen, O_2 - - -	0·74	...
Methane, CH_4 - -	1·16	1·30
Nitrogen, N_2 - - -	56·24	48·80
	100·00	100·00
Heat value of gas in B.Th.U. per cub. ft. - -	135·30	164·40

The heat value of the suction producer plant varies at full load between about 126 B.Th.U. and 138 B.Th.U. per cub. ft., and at light loads falls to about 100 B.Th.U. per cub. ft.; on the other hand, the composition of the pressure producer gas remains at varying loads more constant, and would be, if 164 or 165 B.Th.U. per cub. ft. at full load, probably not less than 145 or 150 B.Th.U. at light load. It follows from this that for suction gas the output of a given gas engine will be less than if pressure gas is used. In practice a margin of about 10 per cent. is allowed as the difference between the two gases.

Since ordinary town gas generally has a heat value of about 600 B.Th.U. per cub. ft., it is necessary to pass four to five times the amount of producer gas through the engine than of coal-gas. The cylinders for a given output must be larger and the ports and valves specially designed to get the best results with the increased flow of gas through them.

It will also be evident, that the amount of air necessary for complete combustion must vary with the composition of the gas. As the engine valves are set to regulate the gas and air admissions for a fixed composition of gas, it means, that with the heat value of the gas varying within 20 to 25 per cent. limits, that is, from 135 B.Th.U. to about 100 B.Th.U., the efficiency of the engine at light loads must be low.

It is not easy to determine the cost of working suction gas plants, since so much depends on the conditions of working and the manner in which the load varies. The stand-by losses are, however, very small compared with steam.

Taking for comparison a 40 KW. generating plant corresponding with that adopted for the town gas plant described in the last chapter, we find that the total cost of purchasing and fixing a plant consisting of suction gas producer, coke scrubber, all connections, gas engine of suitable size running at about 150 or 160 revolutions per

minute, belt-driven dynamo capable of developing as normal full load 40 KW. at about 800 revolutions per minute, all necessary accessories, switchboard, and dynamo connections will be about £750, which compares with £560, the approximate capital cost of a town gas driven plant of similar output.

Large numbers of tests have from time to time been made on suction gas plants to determine the fuel consumption. They show that worked at full load under test conditions the fuel consumption will be from 0·9 to 1·0 lb. of anthracite per B.H.P. hour, or from 1·33 to 1·50 lbs. of anthracite per KW. hour. At light loads this is considerably increased, and under varying conditions, with an average plant load factor of, say, 50 per cent., the fuel consumption of even a pressure producer plant is about 2·75 lbs. per KW. hour, and in this case with a suction plant it will be about 3·5 lbs. of anthracite per KW. hour.

The other items of working cost do not vary much from a town gas driven plant, though, as the attendant has more to look after, he should be a more intelligent man, and his wages may well be 25s. per week instead of 22s.

WORKING COSTS.

The conditions of working are:—

Full load of plant - -	= 40 KW.
Average load - - -	= 20 KW.
Working hours per week -	= 56 hours.
Units generated per week -	= 20 × 56 = 1,120 units.
Plant load factor - - -	= 50 per cent.

The weekly cost of working is :—

	Cost.			Pence per Unit.
	£	s.	d.	
FUEL, 1,120 units at an average of 3·5 lbs. per unit $= \frac{1,120 \times 3·5}{2,240}$ = say $1\frac{3}{4}$ tons of anthracite at 22s. per ton - - - -	1	18	0	0·40
OIL, 1 gal. for twelve hours' running, say 5 gals. at 1s. 8d. per gal. - - - - - -	0	8	4	0·09
WATER for both engine and producer, say 6 gals. per unit = $1,120 \times 6 = 6,720$ gals. at 6d. per 1,000 gals. - - - -	0	3	4	0·03
WASTE, STORES, AND SUNDRIES, say	0	8	6	0·08
LABOUR, one man at 25s. - -	1	5	0	0·27
ALLOWANCE FOR OCCASIONAL SUPERVISION - - - -	0	5	0	0·05
ALLOWANCE FOR REPAIRS, say one week at rate of $3\frac{1}{4}$ per cent. per annum on £750. 0s. 0d. - -	0	9	4	0·10
ALLOWANCE FOR INTEREST AND DEPRECIATION ON CAPITAL OUTLAY, say one week at rate of 10 per cent. per annum on £750	1	8	10	0·33
Total weekly cost - -	6	5	10	1·35

The average cost per unit under these conditions is 1·35d. per unit, as compared with 1·55d. for town gas plant, and 1·47d. for oil engine plant.

For larger plants than, say, 100 B.H.P., it is usual to employ pressure producer gas plants, though it is quite possible to use suction gas plants. In these plants the mixed air and steam is admitted to the generator under

several pounds pressure, and is thus forced through the hot anthracite. The same general chemical action takes place, the gas is richer in carbonic oxide and hydrogen, and the calorific value is from 10 to 15 per cent. higher than the suction producer gas, while at light loads the variation in composition is much less.

The boiler for producing the steam is usually distinct from the generator, the grate being arranged for separate firing. The fuel needed for this boiler is about one-fifth of that used in the producer, though it need not be of the same high quality. In some recent plants arrangements have been made for passing the hot gases on their way from the producer to the coke scrubber through the boiler. This permits the separate firing to the boiler to be stopped when the plant is working, and effects a saving of from 10 to 15 per cent. in the total amount of fuel required by the plant.

A small gasholder to equalise and regulate the supply of gas to the engine forms part of the plant, and in addition to the coke scrubber the gas is passed through layers of sawdust to complete the cleaning process.

So long as anthracite is used as the fuel in these plants there is comparatively little trouble in getting clean gas for the engines, which is the important factor in successful working. If coke is used, the output of the producer is somewhat reduced, and the gas contains a larger proportion of tarry matter, which must be eliminated in the cleaners, or trouble will be experienced in the engines.

Pressure gas plants have in very many cases been in successful use for long periods, giving very little trouble, and requiring few repairs. Their higher heat efficiency over steam plants is a real advantage in places where fuel is dear, and the cost of transport of the fuel from the colliery is a large proportion of the total cost.

A case came under the writer's notice where a steam plant was shut down, and a pressure producer plant used to supply the same load. The fuel consumption fell to

nearly one-third; the steam plant was, however, not working under very favourable conditions.

A test taken over six hours of a plant consisting of a 150 KW. gas engine and Dowson producer, using anthracite coal, gave an overall heat efficiency of 17·5 per cent., from fuel to switchboard, while with steam plant of equal size worked under similar conditions it would be difficult to exceed 9 to 9·5 per cent.

It will be interesting to compare the costs of working by steam plant and a pressure producer plant under the following conditions:—

In a large works fully equipped with electric motors the average motor load is 400 B.H.P. during the day, and say 250 B.H.P. during the night. The maximum load is 600 B.H.P.

Allowing 15 per cent. for losses, these figures represent approximately 350 KW. as the average load during the day, 200 KW. as the average night load, and 530 KW. as the maximum load.

It would be well to instal for this load three units, each of 250 KW., two of which would be able to supply, when working slightly overloaded, the maximum load, the other unit being spare.

These engines might well be of the three-crank vertical high speed type directly coupled to their dynamos.

Two producers should be installed, each capable of making sufficient gas to work two gas engines at full load at the same time, and it will also be necessary to provide a small gasholder for regulating purposes, and ample cleaning apparatus to ensure clean gas.

The capital cost of such a plant fixed complete with all necessary accessories, including switchboards and connections, and the provision of a plain engine house and a roof over producers would be about £16,000.

Working Cost.

The conditions of working are:—

During a twelve-hour day, namely from 6 A.M. to 6 P.M.,

the average load is, say, 400 B.H.P., or 350 KW., and during the night, say, 250 B.H.P., or 200 KW. The works are shut down from 12 noon Saturday till 6 A.M. Monday.

The weekly load is therefore :—

DAYWORK.—		
Monday to Friday	-	$350 \times 12 \times 5 = 21{,}000$ units.
Saturday morning	- -	$350 \times 6 = 2{,}100$,,
NIGHTWORK.—		
Monday to Friday	-	$200 \times 12 \times 5 = 12{,}000$,,
	Total	35,100 units.

which corresponds to an annual output of 1,825,200 units.

Taking the maximum load as 530 KW. the load factor is $\frac{35{,}100 \times 100}{530 \times 168}$ (since $168 =$ the total number of hours per week) $= 39{\cdot}40$ per cent., say 40 per cent.

The plant load factor depends upon the number of hours one or two sets are run, but they should be higher than the load factor, since during the day two sets would be about two-thirds loaded, and during the night one set would be even better loaded.

On a full load test run of such a plant the fuel consumption should not exceed $1\frac{1}{2}$ lbs. of anthracite per KW. hour, and for the working conditions under consideration $2\frac{3}{4}$ lbs. of anthracite per unit should be sufficient.

The producer plant and gas engine both require a good deal of water, part of which in the case of the gas engine is recoverable if cooled. For getting at a cost figure it will be fair to allow 5 gallons of fresh water per unit.

The engines have three cylinders, and require, of course, more oil than the single cylinder engines we have hitherto considered; 2 pints of oil per hour, or 1 gallon for four hours, will be an average amount to allow.

The weekly cost of working would, under the above conditions, be approximately :—

	Cost.			Pence per Unit.
	£	s.	d.	
FUEL, 35,100 units at $2\frac{3}{4}$ lbs. of fuel per unit $= \frac{35,100 \times 2 \cdot 75}{2,240}$, say $43\frac{1}{4}$ tons of anthracite at 22s. per ton - - - - - -	47	11	6	0·32
OIL, say equivalent of one engine working two hundred hours, and requiring 2 pints of oil per hour $= \frac{200 \times 2}{8} = 50$ gals. of oil at 1s. 8d. per gal. - - - - - -	4	3	4	0·03
WASTE, STORES, AND SUNDRIES -	2	10	0	0·02
WATER, say 5 gals. of fresh water per unit $= 35,100 \times 5 = 177,500$ gals. at 6d. per 1,000 gals. - -	4	8	9	0·03
LABOUR— One engineer - £5 0 0 One assistant - - 2 10 0 Two fitter drivers at 35s. 3 10 0 Two drivers at 25s. - 2 10 0 Four producer plant attendants at 22s. - 4 8 0	17	18	0	0·13
REPAIRS— Say one week at rate of $3\frac{1}{2}$ per cent. per annum on £12,000 - £8 1 7 Also one week at rate of 2 per cent. per annum on £4,000 1 10 9	9	12	4	0·06
ALLOWANCE FOR INTEREST AND DEPRECIATION ON CAPITAL OUTLAY, say one week at rate of 10 per cent. per annum on £16,000. 0s. 0d. - - -	30	15	5	0·21
Total weekly cost - -	116	19	4	0·80

This figure of 0·80d. per unit should be attained in actual practice, the allowances made being ample for careful working. Were it possible to increase the load factor of the 530 KW. to 75 per cent. during the working period of one hundred and twenty-six hours per week, the units required would be 50,085 per week, the weekly cost of working would be £132. 10s., but the cost per unit would be reduced to 0·64d. per unit. The actual load factor calculated over the whole one hundred and sixty-eight hours of the week would then be:—

$$\frac{50,085 \times 100}{530 \times 168} = 56 \cdot 23$$ per cent., which compares with the 40 per cent. of the lower output.

It should be noted that whenever the load factor falls, the costs per unit rapidly increase.

Many attempts have been made, some of them with marked success, to modify the gas producer, so that cheap bituminous fuel may be used in place of expensive anthracite. The employment of this material as fuel in an ordinary producer causes the gas to contain a good deal of tarry matter which it is difficult to entirely get rid of.

Dr Mond, who has done much towards perfecting the bituminous fuel producer, mixes the air before admission to the generator with about two and a half times its weight of steam. He also uses the heat which he extracts from the hot gas leaving the generator to heat up the mixed air and steam before admitting it to the producer generator, thus increasing the efficiency of the plant. The result of the presence of such a large quantity of steam is that the temperature of the fuel in the generator is kept comparatively low, and that the nitrogenous matter present in the coal forms, with the hydrogen obtained from some of the decomposed steam, ammonia gas, NH_3. In an ordinary producer this gas would be destroyed as fast as produced, but in the Mond process the temperature of the producer is kept below

that of dissociation of the ammonia, and it passes over with the other gases. Only about one-quarter or one-fifth of the steam is actually used in the producer, the rest passes over with the producer gas, and is condensed in the coolers. The gas is washed by passing it through cooling towers down which dilute sulphuric acid solution flows. This removes all traces of the ammonia, which forms, with the acid, ammonium sulphate, a valuable bye-product, which is removed by crystallisation. In large plants as much as 70 to 80 lbs. of ammonium sulphate per ton of fuel gasified is obtained, and the value of this material is such that it not only pays for the increased cost of the plant, but helps to reduce the cost of the fuel. The low temperature of the producer and the large volume of steam present in the producer result in the proportion of hydrogen gas being higher than with ordinary producer gas.

An average analysis of Mond Gas, as it is often called, used in conjunction with ammonia recovery plant, is :—

	Per Cent. by Volume.
Hydrogen, H_2 - - - -	25·00
Carbonic oxide gas, CO - -	12·00
Carbonic acid gas, CO_2 - - -	16·00
Methane, CH_4 - - - -	2·00
Nitrogen, N_2 - - - - -	45·00
	100·00

Heat value in B.Th.U. per cub. ft. - about 142 B.Th.U.

When this gas is used in gas engines, owing to the large percentage amount of hydrogen which passes into the engine exhaust in the form of steam, and therefore contains its latent heat, the effective heat value is about 10 per cent. lower, or say 130 B.Th.U. per cub. ft.

The cleaning process has to be very thoroughly gone through before the gas is fit for use in order to get rid of the tar, which if present to even a small extent, clogs the engine valves and interferes with their proper working.

Other workers in the same direction have adopted a different method. Instead of keeping the producer temperature low, and working for a gas rich in hydrogen, they have endeavoured to get the gases so hot before leaving the generator that a large part of the carbonic acid gas (CO_2), which is present in Mond gas to the extent of 14 to 16 per cent., is dissociated, and the resultant gas is rich in carbonic oxide gas. This is generally done by reducing the amount of steam mixed with the air to that required for the chemical reactions, and arranging that the gases from the top part of the generator are taken to the bottom of the producer and sent a second time through the hot fuel before passing to the cooling and cleaning plant. This action to a large extent destroys the tar, and so lightens the work to be done by the cleaners.

An average composition of a gas made in this manner would be:—

	Per Cent. by Volume.
Hydrogen, H_2 - - - - -	17·50
Carbonic oxide gas, CO - - -	27·50
Carbonic acid gas, CO_2 - - -	5·10
Methane, CH_4 - - - -	1·50
Nitrogen, N_2 - - - - -	48·40
	100·00

The calorific value of such a gas would be about 170 B.Th.U. per cub. ft., and as the proportion of hydrogen is lower, its net value used for gas engine work is proportionally higher than with Mond gas.

It is with plants of the above types that the gas used in the increasing number of large gas engine installations in this country and abroad are made. When worked on a large scale they are very efficient and economical, and present possibilities of further economies which make them serious rivals to other forms of power producers.

CHAPTER VIII.

INDEPENDENT GENERATING PLANTS—STEAM PLANTS.

The usual Inefficiency of Works' Steam Engines—Typical Works Installation of 40 KW., or, say, 55 B.H.P. Steam Plant—Cost of Working—Comparison with Oil and Gas Engine Plants of Similar Size—Larger Plant of 500 KW. with Spare Engine—Cost of Installation and Working—Comparison with Pressure Producer Plant—Larger Installation for Cotton Mill—Costs of Installation, with and without Spare Plant—Costs of Working in the two Cases—Is Duplicate Plant Necessary?

THE form of prime mover in most general use is the steam engine. In one or other of its varied types, it is to be found in all classes of works and factories. It perhaps reaches its highest efficiency and greatest economy in some of the mill engines of Lancashire and Yorkshire, and in the large generating units in various electricity supply stations in the country. In these places economical working is studied as a science, and excellent results are obtained as a matter of daily practice.

It is, however, far otherwise with the ordinary works or factory engine. It does its work, but at what cost no one inquires, and no one cares. Large sums are paid each week or month for fuel as a matter of course, and it is only when a proposed change of method of working is inquired into, and the actual cost of existing methods are worked out, that the waste is discovered. These remarks include the steam raising plant, one of the most important, but often one of the most neglected, parts of the works equipment. So long as the boiler passes its periodical inspection by the insurance authorities, little thought is given to it, the cheapest form of

labour is secured to look after it, and no care is bestowed on keeping the fuel costs low, or the boiler house clean and tidy, features which have more in common than appears at first sight.

It will be well, therefore, to take two or three definite cases comparable to those chosen in the case of oil and gas, and see what the costs of working are, under certain definite conditions. The approximate costs under different conditions of working can then be very fairly estimated.

The first case may well be that of the small works installation of motors to a total of 45 B.H.P., requiring generating plant of a full load capacity of 40 KW.

The output of the plant must be equal to the maximum load = 40 KW., while we may assume that the average load on the plant during the whole of the working hours is half the maximum, say 20 KW. The working hours are fifty-six per week.

The steam plant would probably consist of a two crank high speed non-condensing engine, direct coupled to a 40 KW. dynamo, together with a boiler either of the Lancashire or Cornish type.

The capital cost of such a plant with a suitable steel chimney, feed water heater, feed pump, the necessary steam piping, switchboard and switchboard connections, would probably be about £1,050. With a simpler type of engine this cost might be reduced £150 or even £200, but the total working cost would be little affected, since the running and repair charges would be slightly higher in the case of the cheaper engine.

No allowance has been made for buildings, since the engine and dynamo could be placed inside the workshop, and the boiler, if there is not a suitable place already in existence near the engine, would be placed as near the engine as possible, and a small building, or in any case a corrugated iron roofing, would be provided, and the cost added to the figure given.

WORKING COSTS.

The conditions of working are:—

Full load of plant - - - - -	= 40 KW.
Average load - - - - - -	= 20 KW.
Working hours per week - - -	= 56 hours.
Units generated per week -	= 20 × 56 = 1,120 units.
Plant load factor - - - - -	= 50 per cent.

The weekly cost of working is:—

	Cost. £	s.	d.	Pence per Unit.
FUEL, say, including Banking Losses and Lighting-up, 10 lbs. of coal per unit = 1,120 units at 10 lbs. of coal = $\frac{1,120 \times 10}{2,240}$ = 5 tons of coal at 9s. per ton - - -	2	5	0	0·48
OIL, say 3 gals. at 1s. 8d. per gal. -	0	5	0	0·05
WASTE, STORES, AND SUNDRIES, say	0	3	6	0·04
WATER, say 6 gals. per unit = 1,120 × 6 = 6,720 gals. at 6d. per 1,000 gals. - - - - - - -	0	3	4	0·04
LABOUR, say equivalent of one man at 24s. - - - - - -	1	4	0	0·26
ALLOWANCE FOR OCCASIONAL SUPERVISION - - - - -	0	2	6	0·03
ALLOWANCE FOR REPAIRS, say one week at rate of 3 per cent. per annum on £1,050. 0s. 0d. -	0	12	1	0·12
ALLOWANCE FOR INTEREST AND DEPRECIATION ON CAPITAL OUTLAY, say one week at rate of 10 per cent. per annum on £1,050	2	0	4	0·43
Total weekly cost - -	6	15	9	1·45

Under these conditions, therefore, and at this output the

relative weekly working costs of the four principal methods of generating electric energy would be :—

	Total Weekly Cost.			Cost per Unit.
	£	s.	d.	d.
Gas engine supplied with town gas - - - - - -	7	5	2	1·55
Oil engine plant - - -	6	16	2	1·46
Suction gas producer plants -	6	5	10	1·35
Steam engine plant - - -	6	15	9	1·45

From these figures it will be seen that it depends largely upon the price of fuel as to whether town gas, suction gas, oil, or steam is the cheapest to use. In the above cases :—

Town gas is taken at 2s. per 1,000 cub. ft.
Oil „ 45s. per ton delivered.
Anthracite „ 22s. „ „
Coal „ 9s. „ „

If the prices are increased to :—

Town gas to - - 2s. 6d. per 1,000 cub. ft.,
Oil to - - - 50s. per ton delivered,
Anthracite to - - 25s. „ „
Coal to - - - 12s. „ „

the costs become :—

	Total Weekly Cost.			Cost per Unit.
	£	s.	d.	d.
Town gas plant - - -	8	5	3	1·77
Oil engine plant - - -	7	0	8	1·50
Suction gas producer plant -	6	11	7	1·40
Steam engine plant - - -	7	10	3	1·61

Speaking generally, in non-mining districts where the cost of carriage of coal greatly affects its price, the cost of town gas is correspondingly high; and oil and suction gas plants

have the advantage, viewed from the cost standpoint; while in places where fuel is cheap, steam plants compare favourably with all other types of plant.

Take next, the case of the large works plant supplied with electric energy from the pressure producer gas plant referred to in a previous chapter. The average motor load is 400 B.H.P. during the day, 250 B.H.P. during the night, and the maximum load is 600 B.H.P.

With the usual allowances for losses, these figures represent about 350 KW. as the average load during the day, and 200 KW. during the night, the maximum load being about 530 KW.

The steam plant for such a works might well consist of three high speed vertical units, each of 250 KW. full load capacity, but capable of working with a 10 per cent. overload. Two of these could supply the maximum load, leaving the other for spare, and at night one set running would usually be sufficient. The plant would work at say 150 lbs. pressure, with steam superheated at the boiler, say 100° Fahr., so as to ensure dry steam at the engine. The steam would be generated in say three boilers of the Lancashire or water-tube type—preferably the former—and a fuel economiser, a boiler feed pump, and the usual accessory plants would be supplied. As a supply of water for condensing is assumed to be available, either from a neighbouring pond or canal, two surface condensers, each capable of easily dealing with the exhaust steam from one 250 KW. set, are supplied, and the circulating water is pumped by means of an electric pump from the canal or pond.

The cost of such a plant complete, including provision for a plain engine and boiler house, and a suitable steel or concrete chimney, would be about £15,000, the exact figure varying with the locality and the particular types of plant selected.

This sum of £15,000 is equivalent to an outlay of £20 per KW. of plant installed, and for this output it should be sufficient.

Mr A. D. Williamson, a few years ago, in a paper read before the Institution of Electrical Engineers, gave some interesting figures as to the total cost of the electrical generating plants at the various works controlled by Messrs Vickers, Sons, & Maxim.

At North Sheffield Works there was a steam plant of 640 KW. capacity, the cost of which was £13,120, or £20. 10s. per KW., and at Erith in Kent there was another steam plant of 600 KW. capacity, and that here the total cost was £13,500, or £22. 10s. per KW.

It will be noticed that both in this case and in that of the pressure gas producer plant for the same work, the spare plant—one unit—forms a large proportion of the total plant, or one-half of the running plant. This provision is necessary in a works running day and night, where the effects of a stoppage might be very serious. Under other conditions the proportion of idle to working plant might be reduced, though it is always a great advantage to have only one size and type of plant, as it minimises the spares necessary to keep in stock, and simplifies the working of the station.

Working Cost.

The conditions of working are the same as with the pressure producer plant, namely:—

During a twelve hour day, say from 6 A.M. till 6 P.M., the average load is 400 B.H.P., or 350 KW., and during the night say 250 B.H.P., or 200 KW. The works are shut down from 12 noon Saturday till 6 A.M. Monday.

The weekly load is therefore:—

Daywork.—			
Monday to Friday	-	$=350 \times 12 \times 5$	$=21{,}000$ units.
Saturday morning	-	$=350 \times 6$	$=2{,}100$ „
Nightwork.			
Monday to Friday	-	$=200 \times 12 \times 5$	$=12{,}000$ „
		Total	$=35{,}100$ units,

which corresponds to an annual output of 1,825,200 units.

Taking the maximum load as 530 KW., the load factor is $\frac{35,100 \times 100}{530 \times 168}$ (since $168 =$ total hours per week) $= 39{\cdot}40$ per cent., say 40 per cent.

Owing to the division of the plant into two running units, one of which is four-fifths loaded at night and the two about two-thirds loaded during the day, the plant load factor should be considerably higher than this 40 per cent.

The coal consumption with this output and under these conditions should not exceed 5 lbs. per unit generated including all banking losses. It is said that at several of the large generating stations in this country the actual coal consumption per unit generated on load factors of 25 to 30 per cent. is under 4 lbs. per unit, but in these cases the output is much larger, and it is possible to have a larger staff, and so to work them up to a higher standard of efficiency.

The weekly cost of working under above conditions would be approximately :—

	Cost.			Pence per Unit.
	£	s.	d.	
FUEL, 35,100 units at, say, 5 lbs. of coal per unit including all banking losses $= \frac{35,100 \times 5}{2,240} = 78{\cdot}3$ tons, say 79 tons of coal at 9s. per ton delivered - - - - -	35	11	0	0·24
OIL, WASTE, AND STORES, allow, say, 0·05d. per unit - - -	7	6	3	0·05
WATER— Allow, say, 5 gals. of fresh water per unit $= 35,100 \times 5 =$ 175,500 gals. at 6d. per 1,000 gals. £4 7 9 Allowance for pumping condensing water, say - - 3 5 0	7	12	9	0·05
Carried forward - -	50	10	0	0·34

		Cost.			Pence per Unit.
		£	s.	d.	
Brought forward - -		50	10	0	0·34
LABOUR—					
One engineer -	£4 10 0				
One assistant - -	2 10 0				
Two fitter drivers at 35s.	3 10 0				
Two drivers at 25s. -	2 10 0				
Four stokers and labourers at 22s. -	4 8 0	17	8	0	0·12
REPAIRS—					
Say one week at rate of 3½ per cent. per annum on £12,000	£8 1 7				
Say one week at rate of 2 per cent. per annum on £3,000	1 3 1	9	4	8	0·06
ALLOWANCE FOR INTEREST AND DEPRECIATION CHARGES ON CAPITAL OUTLAY, say one week at rate of 10 per cent. per annum on £15,000 - - - -		28	16	11	0·20
Total weekly cost - -		105	19	7	0·72

Some figures given on page 98 show that in this case the actual heat efficiency of the entire installation is only 4·26 per cent.

This figure of 0·72d. per unit compares with 0·80d. per unit in the case of the producer plant, but, as it is only in mining districts that the coal could be purchased at the price of 9s. per ton delivered, and each shilling difference in the price of coal per ton adds 0·027d. to the price per unit, it only requires an increase of 3s. per ton in the case of coal without any rise in the cost of anthracite to equalise the cost of the two methods.

In other words, so far as cost is concerned, the figures given show that for the stated conditions of working the

costs are the same when coal can be bought at 12s. per ton, anthracite being 22s. per ton.

Another case where the conditions are different is that of a textile mill where the plant works at or near full load the whole time the mill is open. Here the number of machines are very large, and the power taken by each, small, so that the transmission losses, whether purely mechanical or partly mechanical and partly electrical, form a considerable proportion of the total power required.

For instance in a 100,000 spindle mill of the type so usual in the cotton spinning districts of Lancashire, the actual power needed to be generated to drive the machinery electrically is about 850 KW., the electrical equivalent of the 1,400 I.H.P. usually installed.

The plant needed for such an installation might consist of one steam turbine alternator, capable of developing 850 KW. as normal full load output, supplied with steam from a Lancashire boiler fitted with a superheater in the flue, fuel economiser, and condenser for which water is pumped from a neighbouring pond or stream.

Such a plant completely erected would cost about £11,000, this sum including the turbo-alternator, boiler and condensing plant, switchboard, and connections, a plain engine and boiler house, steel chimney, and all necessary foundations.

WORKING COSTS.

The conditions of working are:—

Normal full load of plant	- -	= 850 KW.
Maximum load	- - - - -	= 850 KW.
Average load	- - - -	= 800 KW.
Working hours per week	- -	= 56 hours.
Units generated per week	= 800 × 56	= 44,800 units.
Plant load factor	- - -	= 94 per cent.
Load factor	- - - -	= 31·37 per cent.

The coal consumption under these conditions should not exceed 3½ lbs. of coal per unit generated, including the amount necessary for banking the fires at night, while with

the one set working always at nearly full load, the oil, waste, and stores charges should be small.

The weekly cost of working would be approximately:—

				Cost.			Pence per Unit.
				£	s.	d.	
FUEL, 44,800 units at $3\frac{1}{2}$ lbs. of coal per unit $= \frac{44,800 \times 3\cdot5}{2,240} = 70$ tons of coal at, say, 9s. per ton -				31	10	0	0·169
OIL, WASTE, AND STORES, say 44,800 units at 0·02d. per unit -				3	14	8	0·020
WATER—							
120,000 gals. for feed at 6d. per 1,000 gals. - -	£3	0	0				
Allowance for pumping condensing water -	3	10	0				
				6	10	0	0·034
LABOUR—							
One engineer -	£3	10	0				
One fitter driver -	1	15	0				
One driver - -	1	5	0				
Two stokers at 25s. -	2	10	0				
				9	0	0	0·047
REPAIRS—							
Say one week at rate of 3 per cent. per annum on £9,000	£5	3	10				
Say one week at rate of 2 per cent. per annum on £2,000	0	15	4				
				5	19	2	0·031
ALLOWANCE FOR INTEREST AND DEPRECIATION CHARGES ON CAPITAL OUTLAY, say one week at rate of 10 per cent. per annum on £11,000. 0s. 0d. - - -				21	3	1	0·116
Total weekly cost - -				77	16	11	0·417

This figure compares with actual results which have been obtained under similar conditions for textile mill work, and also with a cost per unit generated, given by Mr C. Sparks in a paper read before the Engineering Conference of the Institution of Civil Engineers in 1907. Instancing the installation at the Powell Duffryn Colliery in South Wales, where 3,000 KW. of plant has been installed, one of which was a 1,500 KW. set, he stated that the load factor was 36 per cent. and the yearly output 4,800,000 units. This corresponds to a weekly output of 92,300 units. Taking coal at 5s. per ton, the total cost per unit was 0·35d. This was made up of 0·18d. for running costs and 0·17d. for interest and depreciation charges, calculated, as in the above cases, at 10 per cent. per annum on the capital outlay.

If the cost of coal in the above estimate is taken at 5s. per ton delivered, instead of 9s. per ton, the total cost is reduced by £14, or to a weekly cost of £63. 16s. 11d., representing a total cost per unit of 0·342d. per unit.

In an ordinary textile mill it is usually considered safe to instal only one engine capable of dealing with the full output, and to arrange for all cleaning, adjustments, and necessary repairs to be done at night, week-ends, or holidays. There is, however, a feeling in many cases that, where electrical generating plant is concerned, break-downs ought to be guarded against by the provision of spare plant. It will be interesting to note what would be the effect in the above case of installing duplicate plant.

It would not be necessary to provide for actually doubling the generating capacity. The case would be met by installing two turbo-generators, each rated at 500 KW. as normal full load, but capable on emergencies of working for long periods at 850 KW. load. Corresponding boiler capacity divided between two boilers would need to be provided. The capital outlay would be increased by these alterations from £11,000 to, say, £13,000.

The plant load factor would be reduced, since it would

be necessary to run under ordinary conditions both sets, each about three-quarter loaded.

WORKING COSTS.

The working conditions would therefore be:—

Full load plant capacity	- -	= 1,000 KW.
Maximum load -	- - -	= 850 KW.
Average load	- - - -	= 800 KW.
Working hours per week	- -	= 56 hours.
Units generated per week	= 800 × 56	= 44,800 units.
Plant load factor	- - -	= 80 per cent.
Load factor	- - - -	= 31·37 per cent.

On account of the lower plant load factor the coal consumption would be increased to $3\frac{3}{4}$ lbs. per unit, the lubricating cost would be increased, more water would be used, and on account of the extra set an additional stoker would be required.

The weekly cost of working would now be:—

	Cost.			Pence per unit.
	£	s.	d.	
FUEL, 44,800 units at 3·75 lbs. per unit $= \frac{44,800 \times 3·75}{2,240} = 75$ tons at 9s. per ton - - - -	33	15	0	0·180
OIL, WASTE, and STORES = 44,800 units at 0·025d. per unit - -	4	13	4	0·025
WATER— 140,000 gals. for feed at 6d. per 1,000 gals. £3 10 0 Allowance for pumping condensing water - 3 10 0	7	0	0	0·039
LABOUR— One engineer - £3 10 0 One fitter driver - 1 15 0 One driver - - 1 5 0 Three stokers at 25s. - 3 15 0	10	5	0	0·055
Carried forward - -	55	13	4	0·299

							Cost.			Pence per Unit.
							£	s.	d.	
Brought forward - -							55	13	4	0·299
REPAIRS—										
Say one week at rate of 3 per cent. per annum on £10,500	£6	1	2							
Say one week at rate of 2 per cent. per annum on £2,500	0	19	3				7	0	5	0·039
ALLOWANCE FOR INTEREST AND DEPRECIATION CHARGES ON CAPITAL OUTLAY, say one week at rate of 10 per cent. per annum on £13,000 - - - - -							25	0	0	0·132
Total weekly cost -							87	13	9	0·470

The difference in the total weekly cost of working is therefore £87. 13s. 9d., less £77. 16s. 11d. = £9. 16s. 10d., representing £511. 15s. 4d. per annum as the extra annual charge which would be incurred by installing the electrical plant in two sets either of which could be used to supply the whole load if necessary.

In the case of a cotton mill the actual cost of the energy is only one of several items which make up the total cost of power, and a consideration as to whether or not the advantages lie on the side of adoption of the electric drive or not had better be deferred till later, but the figures given above show how low it is possible to reduce the cost of electric energy generated from independent plants when the weekly output is large and the plant load factor high.

A large central power house has some advantages and some disadvantages as against generating plants worked under

above conditions. By reason of its larger output and more specialised attention to details, it will be possible for the actual generating costs to be reduced, but against this saving must be set the losses in distribution and transformation, as well as the interest and depreciation charges on the cost of the cables and the transformers.

If, however, there is a good diversity factor on the whole of the system from which the supply is taken, the proportional sum to be allocated as capital cost to this particular installation will be reduced to such an extent that the total cost per unit, including all interest and depreciation allowances, will be comparable with those obtained by the independent generating plant. It is in the effect on the total cost, of the reduced interest and depreciation charge, that the hope of the power seller mainly lies.

CHAPTER IX.

POWER STATION TARIFFS.

Conditions under which Public Supply of Electric Energy is carried out—By Municipalities—By Public Companies—Effect of these Conditions on Progress—Small Undertakings and their Difficulties—Growth of Power Companies—Varying Prices for Light and Power Units—When Permissible, and to what Extent—Effect of Capital Outlay on Total Cost per Unit—Diversity Factor and its Influence on Proportional Capital Expenditure per Consumer—Flat Rate Tariffs—How to Find an Equitable Tariff—Actual Tariffs—Sliding Scales Justifiable and Necessary—Examples—Comparison of Various Rates at Different Load Factors—Comparison of Various Rates of Charge with Costs of Private Installations—Cost of Production with 100 per cent. Load Factor—Advantages of Supply from Outside Source.

THE financial conditions under which electricity supply undertakings carry on their business must be understood before the question of permissible tariffs is considered.

The power to open up public highways, is in this country vested in the various local authorities, and its exercise by others must be by reason of powers conferred direct by Parliament, which are in practice only granted after the consent of the local authority has been obtained. Unless, therefore, the distribution of power is entirely carried on by means of overhead conductors, or is confined to private premises, public companies or private individuals are compelled to obtain statutory powers in order to carry on their work.

Local authorities, on the other hand, have the power to break up the roads in their own areas, but are precluded

from contracting loans on the security of the rates without the permission of the Local Government Board, which is only given after inquiry and after special Parliamentary powers have been obtained, so that the control in this direction is as effective as in the other.

When, in 1880, the possibility of supplying electric energy from a central source was demonstrated to be a practical possibility, Parliament was desirous of preserving the public from what was felt to be the evil effects of the gas monopoly, and commenced that era of repressive control which has done much to retard the progress of the industry.

In 1881 an Act was passed fixing the procedure to be observed in all applications for permissions to supply electric energy, and making provision for the acquisition of these powers by the local authorities at the end of fourteen years. As, in calculating the purchase price, no allowance was to be made for goodwill, it was necessary for any company to provide for the repayment of all their outlay—excepting its then value, apart from any question of goodwill—within that period. This was found to be impossible, and while the Act was in force no progress was made. At the same time the local authorities were in nearly every case too cautious to run any risks in such an unknown enterprise, and only two or three systems were commenced.

In 1888 the Act was amended by the extension of the first date of compulsory purchase from fourteen to forty-two years, and since then, continuous progress has been made. There is, however, in all private undertakings, the possibility that at the end of forty-two years the system may be compulsorily acquired by the local authority at its then value without allowance for goodwill, and it is necessary for provision to be made year by year against this contingency.

The position to-day, is that outside London nearly all the large towns and many of the smaller authorities own

electricity supply undertakings, and have the sole right to publicly supply electric energy within their own area.

The money to finance these trading undertakings is raised on the security of the local rates after permission has been obtained from the Local Government Board, and sinking funds must be provided to repay these sums with interest within stated periods, ranging up to forty years, and depending upon the use to which the money is to be devoted.

What may, therefore, be termed the standing charges of the industry include in the case of the local authorities the provision of a sinking fund for the redemption of the capital outlay, and in the case of public companies or private individuals the building up of a sufficient reserve fund to compensate for the non-payment of any goodwill value in the event of the local authority exercising its right to purchase at the end of the first term of forty-two years.

These conditions have retarded progress, and in many cases have made the electric light a luxury for the rich on account of its high price, rather than a necessity for all.

Another result has been to make the areas of supply depend upon arbitrary local boundaries, and not upon the economic limits of supply from the generating station. In many places, it has been necessary to place the generating station near the boundary of the supply area with the result that good possible customers within a quarter of a mile in one direction may be prohibited from taking a supply, while in another direction there is a monopoly of supply for four or five miles. This anomaly is perhaps most glaring in London, where it frequently happens, that a would-be customer finds that the nearest generating station has no power to supply him; and he has to go to a station two or three miles away, and, of course, pay his share of the increased distributing charges.

In the smaller towns there are a number of stations—

situated in perhaps the best positions obtainable, but quite unsuitable for really cheap generation of power—where it is useless to hope to produce electric energy at any price low enough to compete with other illuminants unless other uses than lighting can be found for electric energy within the areas of supply.

It was the hope of removing what were seen to be grave defects in the existing law which induced Parliament a few years ago to pass Acts incorporating for different sections of the country a number of so-called power companies. These companies have the right to supply electric energy over wide areas, selling in bulk to existing undertakings, and catering directly only for the large consumer. In some cases the areas of large existing undertakings are excluded from the company's operations; in others, they are not allowed to supply private consumers, but only to deal with authorised distributors. Thus in some places, the large consumer has the option of purchase either from the local undertaking or the power company, in others he is forced to go to the local system however conveniently situated the power company's station or mains may be.

In the Tyneside district, electricity supply on these lines has proved a great success; in Lancashire and Yorkshire power companies are at work making good progress; but in other parts of the country, difficulties of finance have prevented much of a start being made.

The effect of a power load on the load factor of a central station has already been pointed out, and the examples given show the hopelessness of attempting to get really low costs with the ordinary load factors of simply lighting loads which only average 10 to 15 per cent.

The efforts which have been made to improve the lighting load factor by the encouragement of the long hour consumer by means of the maximum demand system have been explained. Its comparative failure is due more to the dislike of the public to a varying charge for the same article, than to

any inherent defect in the principles on which the system is based.

Mention has also been made on page 106 to the plan which has recently been tried at Norwich, to encourage the extended use of electric energy without the necessity of arranging two systems of wiring and having two meters. This system is particularly suitable for private houses. It would require modifying before applying it to large business houses or lock-up shops, where the rateable value of the premises is affected either by position or by the value of the business carried on. The plan is to cover the general charges, which should be borne by the customer, by a charge of 12 per cent. per annum on the rateable value of the house, and to further charge for all energy actually used at a little more than its actual cost of production, namely, one penny per unit. In this way, the customer knows what his fixed rate is, and he also realises that whatever energy he uses, whether for light, power, or radiators, he pays for at a fixed low rate, and that the more he uses, the lower is his average price per unit. It does not matter how the energy is used, so that radiators may be connected to any part of the lighting circuit, and the need for double wiring and two meters is done away with. The supply undertaking is secure of the payment by the customer of his share of the standing charges, whether the customer uses any energy or not. This system should prove popular in encouraging small consumers in moderately rated houses to use electricity freely both for lighting and heating. It has proved a success at Norwich, and is being tried in some other towns, though its extensive adoption for general supply is not at all likely.

It often happens that the tariff proposed for energy supplied for power purposes is only about one-half or one-third of that charged for lighting, even when the energy is generated in the station under similar conditions, is supplied through the same network, and no restrictions are imposed

as to the time during which the power supply is available. It is not easy to completely defend such a policy, although the low charge is made, in the hope that the motors and radiators on the power circuit will use energy during hours when the plant would otherwise be very lightly loaded. In this way the load factor of the system is, on the whole, improved, and so long as the low priced units form but a small part of the total revenue, they do not seriously affect the financial position of the undertaking. Mr J. F. C. Snell, in a paper read before the Institution of Electrical Engineers in the autumn of 1907, carefully considered the power charges made by the various undertakings supplying electric energy in the metropolitan area, and he pointed out that in many cases the tariff did not proportion the standing charges correctly between the two classes of consumers, and that if the power units were in the near future to rapidly increase, and form a large proportion of the total load, the financial prosperity of many of the undertakings would be seriously imperilled.

This state of affairs is not satisfactory, and to a large extent it is true all over the country, the present tendency being to undercharge the power user at the expense of the lighting consumer. In some cases, the undercharge is small, and as the power load increases the decrease in the proportion of general standing charges per unit sold will make the low power rate remunerative, but in every undertaking the aim should be so to proportion the charges and adjust the rates that increase of business to any extent in any direction will strengthen and not weaken the financial position.

Although a tramway load does much to improve the load factor of a generating station, it is noticeable that there is by no means the anxiety to reduce the charge for current for the tramways to anything like the same extent as the supply to the ordinary power consumer. This is probably due to the fact that usually both undertakings belong to the same local authority.

Enough has been said to show how important a factor the capital cost of the undertaking is, in determining the total cost of the units generated and sold. If real success is to be attained this must be kept low, and anything unnecessary in the way of expensive buildings or other unremunerative items must be avoided. Such expenditure acts as a deadweight to the undertaking, and prevents the price at which the energy can be sold being reduced to a sufficiently low point to enable purchased power to compete with independent plants.

It should be remembered, that while on the one hand the conditions under which power is generated in a large central station are favourable to the cost being kept low, there are, on the other hand, the distribution losses to be taken into account. There are the actual losses due to transmitting the energy through the cables to be considered, as well as the interest and depreciation charges on the cables before the customer is reached, and these sums soon neutralise the savings effected in the station itself. Thus taking certain assumptions as to the average load required, the cost of a system, and the cost of generating energy, it is possible to calculate the distances over which purchased energy can successfully compete with independent plants, and it is surprising to find how short these distances are. Mr Snell, in the paper already referred to, placed the distance with a 500 KW. of maximum demand competing with a works plant costing £20 per KW. installed, at less than four miles, while even with a 2,000 KW. demand the distance is under ten miles.

It is in determining what is the capital cost which should be allocated to each consumer, that a high diversity factor is of value. Thus if the total cost per KW. installed of an electricity supply system is £20 per KW., and by reason of the different periods of maximum demand by the various customers the diversity factor is 2·5, it means that each KW. of plant installed at the station is sufficient to

meet the demands of 2·5 KW. of lamps or motors on the premises of a consumer, so that the cost per KW. of plant required to meet the demands of any particular customer is $\frac{£20}{2·5} = £8$ per KW., and not £20 per KW., which would be the capital cost per KW. if the diversity factor of the system were 1. While in industrial districts carrying on various classes of manufacturing operations, a diversity factor of 2·5 is not at all excessive, the usual figure adopted in the case of mixed lighting and power loads is 1·66, and on this basis the £20 per KW. installed at the station would become $\frac{£20}{1·66}$, say £12 per KW. installed on the consumer's premises.

It is, therefore, of the greatest importance that a varied load should be obtained, and not one composed of the same class of customers whose periods of maximum load are likely to coincide. In one case the increase means improved output with no additional capital charges, consequently better diversity factor, less charge per KW. to be allocated to customer, and in addition lower cost per unit generated. In the other case the increase means no improvement in the diversity factor, but an increase in the capital outlay for plant to meet the extra demand on the station, which expenditure has its effect in keeping up the total cost of the energy supplied.

The unremunerative character of some of the plant installed in central stations was strikingly illustrated in a statement made by Mr Talbot, the borough electrical engineer of Nottingham, in a recent Presidential Address to the Municipal Electrical Association. Dealing with the question of the cost of generating energy at different times during the day, he said that the maximum load on the Nottingham station occurred on only one evening of the year, and then only for a very short time, and that the unit at the very top of the peak on the annual load diagram,

which brought in a revenue of fivepence to the Nottingham Corporation, actually cost £45 to produce. This was due to the fact that plant had to be provided to supply the maximum demand, although that maximum demand was only needed once during the whole year.

The following information given in evidence before one of the Parliamentary Committees considering the question of power supply in London during the session of 1908 is of interest in this connection. It relates to the relative proportions of the various items of cost which form part of the total cost of an electricity unit, and is based on the published accounts of seventeen authorised undertakings:—

	Per Cent.
Coal	16·20
Labour, oil, waste, water, stores, and repairs to plant	11·50
Distribution costs, including wages of mains' department and meter readers', rents, taxes, and general charges	17·20
Interest, depreciation, and sinking fund charge on power station on a 7 per cent. basis	26·70
Interest, depreciation, and sinking fund charge on distribution system on a 7 per cent. basis	28·40
Total	100·00

Owing to the high cost per KW. installed of the present generating stations and distributing systems, more than half of the total cost of the units sold are made up of capital charges, or more than three times the cost of the coal.

The actual tariff charged for power varies in nearly every district, the general aim being apparently to arrange as far as possible for a flat rate of about one penny per unit for the small power user. Several of the London and Provincial municipalities supply an unlimited service at this price, to the advantage of the user, and sometimes only the indirect benefit of themselves. In districts where coal is dear there

is no doubt as to the advantage of this rate to the user who only requires a few horse-power for short periods. Printing establishments, laundries, small engineering works such as motor car repair shops, bakers, builders, joiners, confectioners, are only a few of the many trades to be found in almost every town where power is occasionally required, and when these can be supplied from the public mains at one penny per unit there should be little difficulty in securing their custom.

While a flat rate is an advantage to the electricity supply undertaking wishing to secure the short hour consumer, it is a serious handicap when the longer hour consumer has to be considered. The figures that have been given show that the cost per unit generated in an installation varies with the output, and that taking the gas engine installation of 40 KW. full load given on page 116, Chapter V. (Fig. 50), the cost with the various plant load factors of the machines working fifty-six hours per week was:—

100	per cent.	= 2,240	units per week	= 1·01d.	per unit.
75	„	= 1,680	„	= 1·20d.	„
50	„	= 1,120	„	= 1·55d.	„
25	„	= 560	„	= 2·64d.	„

Clearly, if the plant is only used occasionally, there is no question but that the owner would be well advised in at once disposing of his plant, and taking a supply offered him from an outside source at one penny per unit. If, as we have seen, such a customer at that price is a source of loss to the undertaking by reason of his low load factor, he ought to pay more, and can afford to pay more. How shall this charge be assessed? It is most fairly done by some system based on the maximum demand he makes on the system. The user ought to pay his fair share of the standing charges of the generating station due to their always having sufficient generating plant ready to supply his needs.

For the sake of illustration, assume that the weekly charge for standing charges is 2s. 6d. per week per KW. demanded.

The sum to be found each week to cover the standing charges is therefore 2s. 6d. × 40 KW. = £5 per week. In addition to this, assume that a charge of one halfpenny is made for each unit actually used. The weekly bills for the various load factors, worked out on this basis of charge, would be:—

2,240 units per week = equivalent of 100 per cent. Plant Load Factor.

Fixed charge, 40 KW. at 2s. 6d. per KW.	£5	0	0
Variable charge, 2,240 units at ½d. per unit	4	13	4
Total charge - -	£9	13	4

Average price per unit = 1·03d.

The weekly cost of generating these units in an independent installation (see page 112) was £9. 7s. 10d., making an average price per unit of 1·01d.

1,680 units per week = equivalent of 75 per cent. Plant Load Factor.

Fixed charge, 40 KW. at 2s. 6d. per KW.	£5	0	0
Variable charge, 1,680 units at ½d. per unit - - - - - - - -	3	10	0
Total charge - -	£8	10	0

Average price per unit = 1·21d.

The weekly cost of generating these units in an independent installation (see page 113) was £8. 8s. 11d., making an average price per unit of 1·20d.

1,120 units per week = equivalent of 50 per cent. Plant Load Factor.

Fixed charge, 40 KW. at 2s. 6d. per KW.	£5	0	0
Variable charge, 1,120 units at ½d. per unit - - - - - - - -	2	6	8
Total charge - -	£7	6	8

Average price per unit = 1·57d.

The weekly cost of generating these units in an independent installation (see page 114) was £7. 5s. 2d., making an average price of 1·55d. per unit.

560 *units per week = equivalent of* 25 *per cent. Plant Load Factor.*

Fixed charge, 40 KW. at 2s. 6d. per KW.	£5	0	0
Variable charge, 560 units at ½d. per unit	1	3	4
Total charge - -	£6	3	4

Average price per unit = 2·65d.

The weekly cost of generating these units in an independent installation (see page 115) was £6. 3s. 6d., making an average price of 2·64d.

If we suppose that in a month's working the plant load factor in the case of the independent installation was 100, 75, 50, and 25 per cent. for the respective weeks, and that in another month the units purchased were on a similar basis, a comparison of the cost of privately generating the energy and purchasing it at the rate of 2s. 6d. per KW. of maximum demand per week, and one halfpenny per unit would be:—

	Plant Load Factor.	Units.	Private Plant.			Purchased Energy.		
	Per Cent.		£	s.	d.	£	s.	d.
First week - -	100	2,240	9	7	10	9	13	4
Second week -	75	1,680	8	8	11	8	10	0
Third week -	50	1,120	7	5	2	7	6	8
Fourth week -	25	560	6	3	6	6	3	4
Totals - -	...	5,600	31	5	5	31	13	4

Average cost per unit: Private plant, 1·34d.; purchased energy, 1·36d.

If the supply undertaking had charged a flat rate of one penny per unit, the amount they would have received during the month would have been £23. 6s. 8d., which, taking the variable part of the cost of generation and distribution at one halfpenny per unit, would only have left half this sum, or £11. 13s. 4d., towards meeting the standing charges of maintaining sufficient generating plant at the station at the call of this customer, whereas on the other tariff, the sum thus allowed is 2s. 6d. × 4 = 10s. per KW. of demand = £20.

The fixed sum per KW. demanded, which has just been assumed at 2s. 6d. per KW. of maximum demand per week = 2s. 6d. × 52 weeks = £6. 10s. per KW. of maximum demand per annum. This, we have seen, is sufficient to cover the standing charges on an independent generating plant capable of meeting the maximum demand of 40 KW., and is higher than need be allowed if the diversity factor of the public supply system is taken into account. If this is assumed to be 1·66—a fair figure—the standing charge allowance which should be charged by a public supply undertaking is reduced to $\frac{\pounds 6.\ 10s.}{1{\cdot}66}$, or £3. 18s. 4d., say £4, per KW. of maximum demand per annum.

This is the principle which is being adopted by all undertakings which are dependent upon the sale of power for their revenue. The way of expressing the charge varies, but it is necessary to divide it into two factors, one practically to cover the standing charges, the other varying with the number of units actually supplied.

The following are typical of the charges which are being made for purchased power. The Yorkshire Electric Power Co. have powers to supply electric energy over a large part of the manufacturing districts of Yorkshire. They are permitted to charge as a maximum £4 per KW. of maximum demand + 0·85d. per unit actually supplied. They are, however, prepared to accept much lower rates, such as

£4 per KW. + one halfpenny per unit, or for large users even £4 per KW. of maximum demand + one farthing per unit actually used. These figures are very low and are rapidly placing them in a position of superiority to all other competitors. The maximum demand is determined each quarter so that the customer has the advantage of any seasonal variation in his demand for power. The engineer of this Company recently stated in evidence before a Parliamentary Committee that the average price received by the Company was below three-farthings per unit. It is not at all surprising to find that in four years the Company have either connected or contracted for the supply of power to one-quarter of the estimated total motor load of 36,000 HP. in the vicinity of their generating station, among them being the entire power load of seven textile mills.

The Lancashire Electric Power Co., who have operating powers over the southern portion of Lancashire, are pursuing the same policy. They are empowered by their Act of Parliament to charge to large consumers:—

Maximum Demand.	£	s.	d.		
Under 100 KW. =	6	0	0	per KW.	+ 0·45d. per unit.
101 to 200 KW. =	5	0	0	"	
201 to 300 KW. =	4	10	0	"	
301 to 500 KW. =	3	10	0	"	
Over 500 KW. =	3	0	0	"	

They are, however, prepared to supply large users at the same rates as the Yorkshire Co., viz., £4 per KW. of maximum demand plus 0·25d. per unit, and in cases where the maximum load exceeds 500 KW. they are even prepared to make further concessions, so that on a 33 per cent. load factor it may be possible for a large mill to obtain energy at as low a rate as 0·50d. per unit.

In considering these very low rates it is necessary to point out that it is usual for provision to be made in power contracts for increases or decreases in the price per unit to

accord with any wide fluctuations in the market price of coal. Thus if the price per unit is based on a market price of coal at, say, 10s. per ton for coal with a calorific value of 14,000 B.Th.U. per lb., provision would be made for a sliding scale to come into operation when the price of coal varied, say, more than 10 per cent. from this figure. Such a stipulation is only fair, as it would operate with equal force in varying the cost of working a private installation.

The North Metropolitan Electric Power Supply Co. charge £1 per quarter for each KW. of maximum demand plus a rate varying with the character of the load from 0·90d. to 0·40d. per unit.

The St Pancras Borough Council give their customers the option of a flat rate of one penny per unit or a charge of £4 per KW. of maximum demand plus one halfpenny per unit. This option was granted at the time the Administrative County of London Company's Power Bill was before Parliament in 1906, and was taken advantage of by several of their large customers. Time, however, showed that their load factor was so low that their quarterly bills under this system were considerably increased, so that it is not surprising to hear they have all reverted to the old flat rate of charge.

The Shoreditch Borough Council, who have a large number of small power users on their mains, charge £4 per KW. of maximum demand plus three-farthings per unit if the consumption is less than 75,000 units per annum, charging at the rate of £4 per KW. of maximum demand plus one halfpenny per unit when the consumption exceeds that amount.

The maximum charges proposed in the various Power Bills for London which were presented to Parliament in the session of 1908 are also on the same lines.

Thus, in the London and District Company's Bill, which provides for a supply to authorised distributors and large power users, the following rates were proposed :—

For a supply of high tension three-phase current to

customers whose maximum demand exceeded 250 KW.—£3 per KW. of maximum demand plus one farthing per unit actually supplied.

For a supply of low pressure three-phase alternating current to customers whose maximum demand exceeded 250 KW.—£3. 10s. per KW. of maximum demand plus 0·30d. per unit actually supplied.

For a supply of direct current to customers whose maximum demand exceeded 250 KW.—£4. 10s. per KW. of maximum demand plus 0·33d. per unit actually supplied.

There are in the Bill proposals to enable certain additions to be made to the above rates for customers whose demand is less than 250 KW., and it is stated that the Company propose that in practice the prices shall be less than the above maximum rates.

In the Bill promoted by the associated existing London companies, now passed into law, the proposed charge to authorised distributors for a bulk supply was stated to be £5 per annum per KW. of maximum demand plus 0·35d. per unit supplied, and it was finally decided to modify the maximum rates included in the various Acts under which the companies operate so that the price for power units shall not exceed £6. 15s. per annum per KW. of maximum demand plus one halfpenny per unit used.

The proposed charges in the abortive Bill proposed in 1907 by the London County Council for power supply in London were on the same lines.

Little information is obtainable as to the exact rates charged by the Newcastle-on-Tyne Electric Supply Co. and its allied companies, but their plan of proportioning the rate of discount to the output accomplishes the same purpose.

It will be well to select two or three of these various tariffs, and see how they compare with each other with different load factors.

The rate of £4 per KW. of maximum demand plus one halfpenny per unit may be taken as representing the usual

charge of a power company to an ordinary consumer, and the rate of £4 per KW. of maximum demand plus one farthing per unit as the charge to a large long hour consumer such as a cotton mill or large engineering works. These compare with each other and with a flat rate of one penny per unit as follows, taking the working load as requiring one kilowatt:—

Working Hours per Day.	Working Hours per Year.	Units Used per Year.	Per Cent. Load Factor.	Cost per Unit.		
				Flat Rate.	£4 per KW. of Demand plus ½d. per Unit.	£4 per KW. of Demand plus ¼d. per Unit.
				d.	d.	d.
1	365	365	4·16	1·00	3·13	2·88
2	730	730	8·33	1·00	1·81	1·56
3	1,095	1,095	12·50	1·00	1·38	1·12
4	1,460	1,460	16·66	1·00	1·16	0·91
5	1,825	1,825	20·83	1·00	1·02	0·77
6	2,190	2,190	25·00	1·00	0·94	0·68
7	2,555	2,555	29·16	1·00	0·87	0·63
8	2,920	2,920	33·33	1·00	0·83	0·58
9	3,285	3,285	37·50	1·00	0·79	0·54
10	3,650	3,650	41·66	1·00	0·76	0·51
11	4,015	4,015	45·83	1·00	0·74	0·49
12	4,380	4,380	50·00	1·00	0·72	0·47
15	5,475	5,475	62·50	1·00	0·67	0·42
18	6,570	6,570	75·00	1·00	0·64	0·40
21	7,665	7,665	87·50	1·00	0·62	0·38
24	8,760	8,760	100·00	1·00	0·61	0·36

These figures are shown graphically on Fig. 52. With the higher rate of charge, namely, £4 per annum per KW. of maximum demand plus one halfpenny per unit, the curves show that at all load factors less than 21 per cent., or five hours' work per day, the flat rate of one penny per unit is the cheaper to the customer, while at higher load factors the advantage of the varying scale to the supply company becomes more and more pronounced, till with a

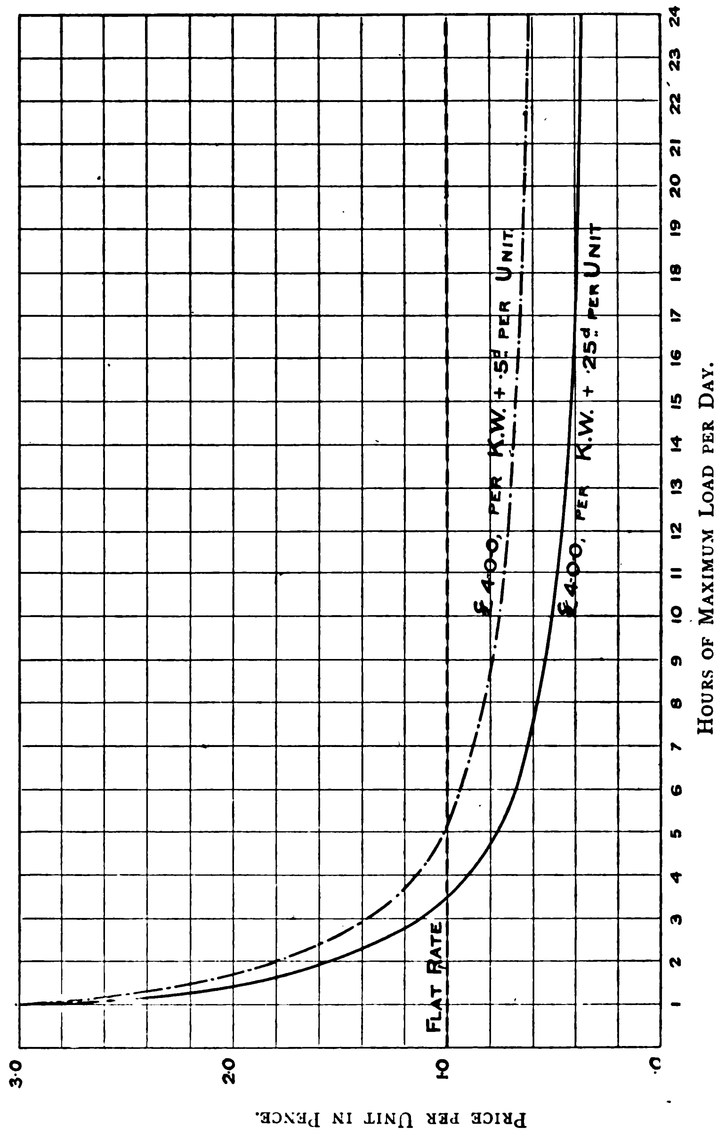

Fig. 52.—Curve showing Price per Unit of Electric Energy for Maximum Loads maintained for Varying Number of Hours per Day under Different Tariffs.

continuous twenty-four hour load, it is 39 per cent. lower than the flat rate.

With the lower rate of £4 per annum per KW. of maximum demand plus one farthing per unit used, the lines cross at 16 per cent. load factor, or a little less than four hours per day, the advantage to the supply company of the varying scale increasing until at 100 per cent. load factor it amounts to 64 per cent.

In dealing with charges made on this basis it is important to remember the effect of any increase in the maximum load on the annual bill. Thus, if in a works, motors to an aggregate demand of 40 KW. are one day simultaneously overloaded 25 per cent. for an hour, the maximum demand on the station will be increased from 40 KW. to 50 KW., or by 10 KW., and the annual bill by $10 \times 4 =$ £40; or, if the maximum demands are taken quarterly, by £10.

In larger installations the effect of careless simultaneous overloading of the system may make a very serious addition to the maximum demand, with a corresponding increase in the total cost of power.

As a result of the low price at which energy can be purchased by consumers having very high load factors on the lowest of the above scales, it is interesting to note that a calcium carbide manufacturing company who require large quantities of electric energy have established a factory close to the Yorkshire Power Co.'s Thornhill generating station, in order to avail themselves of this low price, which is still further reduced on the manufacturing company undertaking so to arrange their work that no energy is required during the ordinary peak load hours.

Assume that in all cases where the maximum demand is less than 100 KW., the charge will be £4 per annum per KW. of maximum demand plus one halfpenny per unit used, and in other cases the same sum per KW. of maximum demand plus one farthing per unit. The following is a comparison of the cost of purchased energy with the prices obtained in earlier chapters for independent plants:—

(A.) GAS ENGINE INSTALLATION (pages 112-115, Chapter VI.).

Maximum load -	40 KW.			40 KW.			40 KW.			40 KW.		
Average load -	40 KW.			30 KW.			20 KW.			10 KW.		
Working hours per week - - -	56			56			56			56		
Units per week -	2,240			1,680			1,120			560		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Price, gas, per 1,000 cub. ft. - -	0	2	0	0	2	0	0	2	0	0	2	0
Total cost of working per week, including proportion of 10 per cent. per annum on capital outlay for interest and depreciation -	9	7	10	8	8	11	7	5	2	6	3	6
Weekly cost if energy could be purchased at rate of 1d. per unit flat rate - -	9	6	8	7	0	0	4	13	4	2	6	8
Weekly cost if energy could be purchased at £4 per KW. of maximum demand + ½d. per unit -	7	14	11	6	11	7	5	8	3	4	4	11
Rate per unit if energy purchased on this basis -	0·83d.			0·94d.			1·16d.			1·82d.		
Rate per unit at which energy can be generated in private installation - - -	1·01d.			1·20d.			1·55d.			2·64d.		

(B.) Other Types of Plant.

	Oil Engine Plant.	Producer Gas Plant.	Steam Engine Plant.
Reference to details	Page 145	Page 154	Page 165
Maximum load -	40 KW.	40 KW.	40 KW.
Average load - -	20 KW.	20 KW.	20 KW.
Working hours per week - - -	56	56	56
Units per week -	1,120	1,120	1,120
Cost of oil per ton -	45s.	...	...
Cost of anthracite per ton - -	...	22s.	...
Cost of coal per ton	...	...	9s.
Total cost of working per week, including interest and depreciation at rate of 10 per cent. per annum on capital outlay	£ s. d. 6 19 10	£ s. d. 6 5 10	£ s. d. 6 15 9
Rate per unit -	1·47d.	1·35d.	1·45d.
Weekly cost if energy could be purchased at 1d. per unit - -	£ s. d. 4 13 4	£ s. d. 4 13 4	£ s. d. 4 13 4
Weekly cost if energy could be purchased at rate of £4 per KW. of maximum demand + ½d. per unit - - -	£ s. d. 5 8 3	£ s. d. 5 8 3	£ s. d. 5 8 3
Rate per unit do.-	1·16d.	1·16d.	1·16d.

(C.) Producer Gas and Steam Installations for Large Works.

	Pressure Producer Gas Plant.	Steam Engine Plant.
Reference to details - -	Page 158	Page 170
Capacity of plant - -	750 KW.	750 KW.
Maximum load - -	530 KW.	530 KW.
Average load factor -	say 40 per cent.	say 40 per cent.
Working hours per week	126	126
Units generated per week	35,100	35,100
Cost of anthracite per ton	22s.	...
Cost of coal per ton -	...	9s.
Total cost of working per week, including interest and depreciation at rate of 10 per cent. per annum on capital outlay - - -	£ s. d. 116 19 4	£ s. d. 105 19 7
Price per unit - -	0·80d.	0·72d.
Weekly cost if energy could be purchased at flat rate of 1d. per unit	£ s. d. 146 5 0	£ s. d. 146 5 0
Weekly cost if energy could be purchased at rate of £4 per KW. of maximum demand + ¼d. per unit - -	£ s. d. 77 6 8	£ s. d. 77 6 8
Rate per unit do. -	0·53d.	0·53d.

(D.) LARGE STEAM PLANTS FOR TEXTILE MILL WORK.

	One 850 KW. Set.	Two 500 KW. Sets.
Reference to details -	Page 172	Page 175
Capacity of plant - -	850 KW.	1,000 KW.
Number of units - -	1	2
Maximum load - -	850 KW.	850 KW.
Average load - -	800 KW.	800 KW.
Working hours per week	56	56
Units generated per week	44,800	44,800
Cost of coal per ton -	9s.	9s.
Total cost of working per week, including interest and depreciation charges at rate of 10 per cent. per annum on capital outlay -	£ s. d. 77 16 11	£ s. d. 87 13 9
Price per unit - -	0·417d.	0·470d.
Weekly cost if energy could be purchased at rate of £4 per annum per KW. of maximum demand + 0·25d. per unit - - - -	£ s. d. 112 1 0	£ s. d. 112 1 0
Price per unit - -	0·60d.	0·60d.

The reason that the cost per unit in the last case, where 44,800 units are purchased each week, is higher than in the previous case, where only 35,100 units were purchased weekly, is due to the lower load factor. The textile mill only works in the daytime, or 56 out of the possible 168 hours in a week, while the engineering works worked 126 hours out of the 168 hours.

It is very probable that for a load of this character a power company would be willing to accept an inclusive

price of 0·50d. per unit or even less on a guaranteed output of 2,000,000 units per annum, or 40,000 units per working week. If so, the weekly cost of purchased energy would be in this case 44,800 units at 0·50d. per unit = £93. 6s. 8d.

All the above figures can, of course, be modified to suit actual conditions, but they show what are the prices which must be aimed at if the question of power supply is to be settled on purely cost lines.

The instances taken have in each case been those likely to be met with in ordinary works practice. Before finally leaving this branch of the subject it will be interesting to take the cases of the producer gas and steam plants for the large engineering works and see what the cost per unit would have been if it had been possible to work the plant at its full running load of 500 KW. for the whole of the 168 hours in the week. Three 250 KW. sets are installed in each case, so that there is 50 per cent. of spare plant to meet emergencies. These conditions are never met with in practical work, the nearest approach being some chemical processes where power is constantly required and work must be carried on.

PRODUCER PLANT.—The total capital outlay on the plant has been taken as £16,000.

WORKING COST.

The assumed conditions of work are:—

Maximum load - - - - -	= 500 KW.
Average load - - - - - -	= 500 KW.
Number of working hours per week -	= 168 hours.
Units per week - - = 500 × 168	= 84,000 units.
Load factor calculated on running plant - - - - - -	= 100 per cent.

The anthracite required under these conditions should not exceed 1·75 lbs. per unit, and the fresh water required per unit would be reduced to 4 gallons.

The weekly cost of working would be approximately—

	Cost.			Pence per unit.
	£	s.	d.	
FUEL, 84,000 units at $1\frac{3}{4}$ lbs. of fuel per unit $= \frac{84,000 \times 1{\cdot}75}{2,240} =$ say 66 tons of anthracite at 22s. per ton - - - - -	72	12	0	0·207
OIL, say $1\frac{1}{2}$ pints per engine per hour = 2 engines $= \frac{2 \times 168 \times 1{\cdot}5}{8}$ = say 63 gals. at 1s. 8d. per gal. -	5	5	0	0·015
WASTE, STORES, AND SUNDRIES -	5	0	0	0·014
WATER, say 4 gals. of fresh water per unit = 84,000 × 4 = 336,000 gals. at 6d. per 1,000 gals. - -	8	8	0	0·024
LABOUR—				
One engineer - £5 0 0				
One assistant - - 2 10 0				
Two fitter drivers at 35s. - - - 3 10 0				
Three drivers at 25s. - 3 15 0				
Six producer plant attendants at 22s. - 6 12 0				
Two labourers at 20s.- 2 0 0	23	7	0	0·066
REPAIRS—				
Say one week at rate of $3\frac{3}{4}$ per cent. per annum on £12,000 £8 13 1				
Also one week at rate of 2 per cent. per annum on £4,000 1 10 9	10	3	10	0·029
ALLOWANCE FOR INTEREST AND DEPRECIATION CHARGES ON CAPITAL OUTLAY, say one week at rate of 10 per cent. per annum on £16,000 - - - -	30	15	5	0·089
Total weekly cost - -	155	11	3	0·444

STEAM ENGINE PLANT.—In this case the capital cost was taken at £15,000.

WORKING COST.

The assumed conditions of work are:—

Maximum load - - - - -	= 500 KW.
Average load - - - - - -	= 500 KW.
Number of working hours per week -	= 168 hours.
Units per week - - - - -	= 84,000 units.
Load factor calculated on running plant - - - - - -	= 100 per cent.

The coal required per unit under these ideal conditions should not exceed 3 lbs. per unit, and the oil, waste, and stores allowance should be reduced to 0·025d. per unit.

The weekly cost of working would be approximately:—

	Cost. £	s.	d.	Pence per Unit.
FUEL, 84,000 units at 3 lbs. of coal per unit $= \frac{84,000 \times 3}{2,240} = 112\frac{1}{2}$ tons at 9s. per ton - - - -	50	12	6	0·145
OIL, WASTE, AND STORES, say 84,000 units at 0·025d. per unit -	8	15	0	0·025
WATER— Say 4 gals. per unit = 84,000 × 4 = 336,000 gals. at 6d. per 1,000 gals. £8 8 0; Allowance for pumping condensing water, say - - 5 0 0	13	8	0	0·038
Carried forward - -	72	15	6	0·208

		Cost.			Pence per Unit.
		£	s.	d.	
Brought forward - -		72	15	6	0·208
LABOUR—					
One engineer -	£4 10 0				
One assistant - -	2 10 0				
Two fitter drivers at 35s. - - -	3 10 0				
Three drivers at 25s. -	3 15 0				
Six stokers, &c., at 22s.	6 12 0				
		20	17	0	0·060
REPAIRS—					
Say one week at rate of $3\frac{3}{4}$ per cent. per annum on £12,000 -	£8 7 10				
Say one week at rate of $2\frac{1}{2}$ per cent. per annum on £3,000	1 3 1				
		9	10	11	0·027
ALLOWANCE FOR INTEREST AND DEPRECIATION CHARGES ON CAPITAL OUTLAY, say one week at rate of 10 per cent. per annum on £15,000 - - -		28	16	11	0·082
Total weekly cost -		132	0	4	0·377

It might be possible with the use of a smaller staff, or by reason of the repair bill being lower than that allowed, or by dispensing with the 50 per cent. spare plant allowance, to reduce these costs, but on the bases that have been taken they are the lowest which could be attained with those particular plants.

Very little reference has been made to what may be termed the collateral advantages of purchase from an outside source, such as :—

1. Increased certainty of supply.

2. Reduced anxiety to works management staff due to absence of generating machinery from the works.

3. Reduced outlay on power plant, liberating capital which can be better employed in increasing size of works and consequently output and net profit.

4. The space needed for the generating plant and accessories can be utilised for directly productive purposes.

5. The rateable value of the premises is reduced by the cost of the plant, and consequently there is a distinct annual saving in the rates which may fairly be credited to the cost of the purchased energy.

These advantages are very real, but their value depends so much on the position of the works, the character of the processes carried on, and cost of space, that their valuation must be left to the manufacturer himself. It is this sum which in many cases turns the scale in favour of purchase of energy from an outside source.

SECTION III.—THE APPLICATIONS OF ELECTRIC POWER.

CHAPTER X.

THE USE OF ELECTRIC POWER IN TEXTILE FACTORIES.

Importance of Small Economies in the Textile Industry—Evolution of Present Methods of Working—Need for Steadiness of Drive at Machines—Superiority of the Electric Drive in this Respect over other Methods—Increased Output and Improved Quality with Electric Drive—Summary of Advantages and Disadvantages of Electric Driving—Types of Motors for Different Classes of Work—Arrangement of Motor Drives to get Best Results—Consideration of Cost of Installing the Electric Drive—Relative Costs of Maintenance—Should Electric Energy be Generated or Purchased?

FROM whatever standpoint they are considered, the textile industries are amongst the most important in the country. The value of the finished products, the amount of capital invested, the number of persons directly or indirectly dependent upon them, and the total amount of power required to carry them on, are in each case so great that it is difficult to realise their true significance. It is stated that in Lancashire alone, there is nearly a million and a half horse-power of steam plant in use for driving mills, and an examination of the conditions under which they are working reveals an average efficiency and an adaptation of means to ends unequalled in any other of our great industries.

There is no need here to explain how it is that certain areas in this country have won a reputation which has secured them the greater part of the textile trade of the world. It is sufficient for our purpose to point out that

the difference between the price at which raw cotton can be purchased by the mills, and that which can be obtained for finished cotton goods, is so small that it is only by the closest attention to detail that the business can be successfully carried on.

The result of many years' work under these conditions has been to produce a generation of workers who are unexcelled in their ability to operate textile machinery, as well as a race of works' managers who thoroughly understand the importance of small economies. It is perhaps natural that, accustomed as they are to get the most and the best out of the machinery they have used for many years, they are slow to make changes and adopt new methods.

This characteristic was very apparent twenty-five years ago, when rope driving was first proposed. The mill owners and managers were so used to gear-wheel driving —and it is only fair to say had brought it to such perfection —that so far as regards efficiency, there was little to choose between the two systems, but the indirect advantages of rope driving with its greater flexibility and higher shafting speeds were so marked that eventually gear wheels were discarded as far as possible, and rope driving substituted.

The same process is being gone through with electric driving. Here again the actual gain in efficiency is not the factor which will eventually decide the question. It is the larger output and improved quality of the finished product which will force the manufacturer to employ electric motors. There are other advantages which are very real and will be noticed later, but the possibility of working the machines at a more uniform and higher average speed is the most important.

Textile mills may be divided into three classes—spinning mills, where the cotton or wool after a careful preparatory treatment is spun into thread; weaving mills, where the thread is woven into calico or cloth; and dyeing sheds, where the material is dyed or printed ready for the market.

Taking spinning mills first, we find that, speaking generally, cotton mills are located in Lancashire, principally round Manchester and its vicinity, where it is said the general humidity of the climate is very suitable for this work, while woollen mills cluster together in South Yorkshire.

We have here a number of different machines which, for the most part, need a constant speed. In some of them, notably in the carding machines, the intermediate machines, including the combing, roving, slubbing, and intermediate frames, as well as the actual spinning machines, whether ring or mule type, it is important that certain maximum speeds shall not be exceeded. These maximum speeds are determined by the permissible strain on the threads, to exceed which, causes an undue amount of breakage. It naturally follows that these maximum speeds vary with the character of the work.

The aim in spinning mills is, therefore, to maintain as steady and constant a drive as possible. A heavy fly-wheel and a sensitive governor is usually placed on the main engine, and the whole is so well designed and constructed that the variations in speed at any part of the revolution of the engine do not exceed 3 per cent. This is an excellent result, but the ropes and the intermediate shafting between the engine fly-wheel and the line of shafting actually driving the machines, slip and cause the fluctuations at the machine pulleys to be much more pronounced, often amounting to 15 or 20 per cent.

This is often not fully realised in practice, but that it is actually the case is well illustrated on some records shown by Mr W. B. Woodhouse some months ago in a paper read before the Bradford Engineering Society. These records were taken on a sensitive and accurate speed recorder.

Fig. 53 shows the difference which the slip of the ropes and intermediate shafting, make between the drive of the engine and the countershafting actually driving a number

of looms. The engine variation is 3 per cent., the variation at the machines 18 per cent.

This particular mill was changed over to the electric drive, and Fig. 54 shows the same countershafting driven by

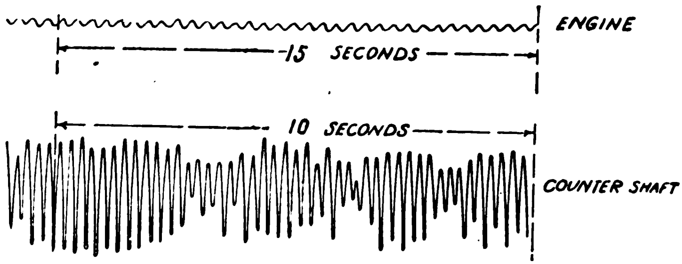

Fig. 53.—Comparison of Variations of Speed at Engine Fly-wheel and Machine Countershaft.

an electric motor. The speed variation has been reduced from 20 per cent. to less than 4 per cent.

Another case is that of a countershaft driving a mule machine. Here it is very important that the maximum speed shall not be exceeded, or the number of thread

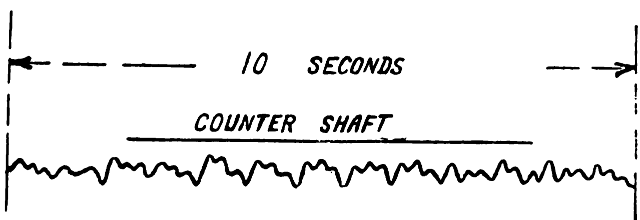

Fig. 54.—Diagram showing Variation of Speed on same Machine Countershaft after conversion to Electric Driving.

breakages rapidly increases. Before electrification, as shown in Fig. 55, the variation was 15 per cent. Afterwards it did not exceed 3 per cent.

A further instance shows a countershaft driving a carding

machine. Here, as seen in Fig. 56, the speed variation was reduced from 7 per cent. with the steam drive to ½ per cent. when motor driven.

These typical instances prove that it is possible with an electric motor to run the countershafting, driving the

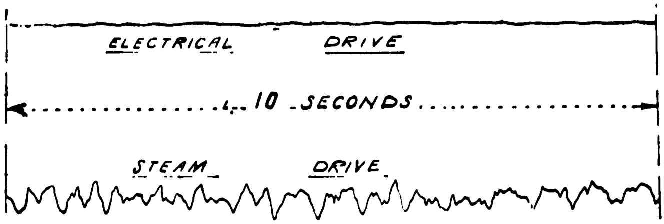

Fig. 55.—Comparison of Variation of Speed on Mule Spinning Machine Countershaft before and after conversion to Electric Drive.

machines in a mill, under the same conditions as to speed variation as the fly-wheel of the main engine. That is, to eliminate the variations from steady running due to slip and other causes in the intermediate ropes, belts, and shafting. These results may be obtained with judicious

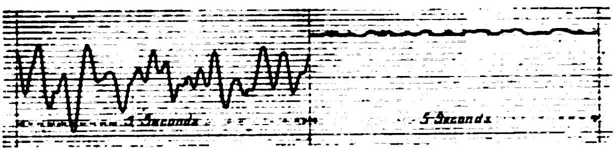

Fig. 56.—Comparison of Variation of Speed on Carding Machine Countershaft before and after conversion to Electric Driving.

grouping of the various machines, and in some instances by adopting the individual drive. The extent to which in practice it is advisable to group machines, or to separately drive them, so as to provide the greatest uniformity in speed depends upon the individual conditions. If one large

motor were substituted for the main engine, obviously no improvement in this direction would result, while to go to the expense of separate motors for each machine would be unnecessary and unwise. The general fact remains that with an electric drive it is possible, without exceeding the permissible maximum speed, to increase the average speed of any group of machines 7½ to 10 per cent., thereby not only increasing the output, but because of the steadier drive, obtaining a more valuable finished product.

Manufacturers who have adopted electric driving are naturally averse to publishing the exact extent to which this is the case, but they will fully admit 3 per cent. in conversation and make use of a 5 per cent. increase as the basis of their own calculations; so there is no doubt as to the reality of the improvement. With certain carding machines the number of cards made per day was 25 per cent. higher after conversion, and with other individual machines the gain was also very marked. In places where only part of the machines have been changed over from steam to electric drive, the workers have made it a distinct grievance, and those operating the steam driven machines have petitioned for the changeover to be completed because of the greater ease of working with the steadier drive of the electric motor.

There are, however, other advantages which can be obtained by the adoption of the electric drive in textile factories besides the greater uniformity of countershafting speed.

These may be summarised as follows:—

A. **Greater Flexibility in the arrangement of the Mill.**—A steam driven mill usually consists of several floors with the engine placed in the basement. The countershafting is so connected by ropes or belts that it is run from one point on each floor by ropes from the engine main pulley. The distance between the engine and driven machine, as well as their relative positions, are

therefore limited by the conditions imposed by the possibilities of the mechanical drive.

In many cases, only part of a site can be utilised owing to this condition, and it is easier to wait for extensions until an entire new mill can be built, than to gradually extend an existing one. With electric driving, the only connection between the motor and the generator are two or three flexible copper conductors which can be taken to any spot or any distance. The machinery may be placed in any convenient position, and extension machines may be placed in separate buildings as desired, without reference to the position of the main engine.

B. **Reduction of Shafting.**—The general practice in steam driven mills is to arrange for the countershafting driving the various machines to run at speeds usually varying between 160 and 200 revolutions per minute. With electric driving it is possible, and in many cases preferable, to arrange the machines in groups driven from a countershaft which runs at about 500 or 600 revolutions per minute. This countershaft may be driven by one motor either direct coupled, or connected to it by belts, chains, ropes, or even spur gearing. The higher speed at which the shafting runs allows of much smaller and lighter shafting being used, the pulleys, hangers, and bearings being correspondingly lighter. This reduction in the amount, size, and weight in the mill has an appreciable effect on the cost of maintenance, while the saving in their cost goes far towards purchasing the necessary motors and accessories.

C. **Independence of Different Sections of the Mill.**—The fact that in some cases each machine, and in any case each group of machines, is driven by an independent motor makes it possible to run parts of the mill or any set of machines separately. As the shafting losses in a mill requiring 1,000 I.H.P. may easily be 300 I.H.P., the importance of this will at once be realised.

D. **Improved General Efficiency.**—It is easy to

place a recording wattmeter in the circuit of any motor, and by examining its record to see exactly what energy has been used. This information may be very valuable, as it enables faults in the machines to be located and remedied, and at the same time enables the cost of operating separate machines to be calculated. Incidentally records of this description tell whether the machines are worked at their normal rate during the whole of the day. In many cases it has been shown that in the early morning and after each stoppage for meals it takes some time to get properly to work, and by attention on the part of the managers and foremen, it has been possible in many cases to save half to three-quarters of an hour per day. This means a considerable difference in the annual output, and well repays the extra trouble involved in insisting upon the workers promptly commencing work.

E. **Purchase of Energy.**—In a number of districts it is now possible to purchase electric energy at a reasonable rate from some public supply. Where this is the case there is a saving of about 10 per cent. of the cost of building and equipping the mill, due to the absence of the chimney, boiler house, steam raising plant, steam engine with its accessories, rope race, &c., and the capital thus saved can be invested in laying down additional machinery which enables the profits earned by a given outlay to be increased. As in all probability the sum paid for energy will be higher than the price at which it could be generated on the site, this saving is reduced to that extent, but it remains in many cases a real factor in determining how the mill shall be driven.

F. **Reduced Liability to Stoppage of Mill.**—In a mill driven either from its own steam plant or from its own electrical generating plant there is always a chance that any fault either in the boilers or steam engine may necessitate the stoppage of the whole mill. If the mill is run electrically, and especially if the electric energy is purchased, the

risk of total stoppage is practically eliminated. Should any motor develop a fault it is only the machines it is driving that are affected, and at the worst it is the work of a very short time for the motor to be removed and another one put in its place. Duplicate mains and ample spare plant render the failure of a public supply of electric energy a remote contingency.

G. **Type of Steam Engine**.—The steam turbine affords a more satisfactory prime mover for textile machines than the slow speed reciprocating engine, on account of its more even turning moment. By reason of its high speed it is not easy to arrange to use them in combination with the usual mechanical drives. They can, however, be easily connected to electrical generators and the advantage of their steady torque thus made use of. This is one of the reasons why, when works electrical generating plants are installed in mills, turbine driven generators are usually preferred, and in large power stations the power supply is often obtained from turbine driven plant. In one district where the central station has both turbine and reciprocating engine driven plant, the mills can tell from the steadiness of the drive when the turbine, and when the reciprocating engine sets, are being run. This is one of the causes contributing to the steady electric drives shown in Figs. 53 to 56.

The induction type of motor, especially when run on two or three phase circuits, possesses many advantages for textile mill work. It has practically a constant speed under all conditions of load with a well-defined maximum, has fair starting torque, and in the squirrel cage pattern there are no rubbing contacts carrying current. Its simplicity and robustness under working conditions are great recommendations in its favour.

It must be remembered that the temperature of many of the rooms in the mill is about 85° Fahr., especially near the ceilings, where the motors are often placed. The motors

have to run under these conditions for the whole of the working hours at practically full load, so that ample margin in size must be allowed. Some of the processes carried on in textile mills need a humid atmosphere, and this has to be produced by artificial means, thus increasing the need for care in the selection of the pattern of motor adopted. It is necessary also to see that the motors are protected by gauze coverings to all openings from the cotton dust which, in some of the rooms, is ever present.

Where the machines are run in groups, and the shafting runs in parallel lines, it is sometimes possible to extend the shafts and place the motors in passages outside the machinery rooms, where there is better ventilation and greater freedom from dust. If this is not possible, it is occasionally advisable to enclose the motors in metal cases and arrange for ventilation by bringing in air from outside the mill, providing a draught by conducting the warmed air, after it passes through the motor, through other pipes to a point outside the mill. It is only in special rooms that such precautions are needed, in the majority of cases it is sufficient to simply place the motor in the most convenient position for the work.

The question of arrangement of motor drives is all important, and upon this depends to a large extent the economies to be effected. In the case of altering an old mill from mechanical to electrical drive, there is often little choice. The machines are all fixed in place, and a condition of the changeover is that the working of the mill shall not be interfered with. Group driving is, therefore, a necessity, and the only thing to do is to choose the best positions for the motors, and subdivide the shafting to suit. When new mills are equipped there is more choice, and the machines may be grouped together or run separately as deemed most desirable.

The machinery to be driven in a spinning mill divides itself into five classes :—

There are, first, the machines in the preparation room for

opening up and cleaning the raw cotton. These machines take on an average 4 to 6 B.H.P., run at fairly high speeds, and are generally arranged in groups run from one motor by countershafting and belts, though it is only questions of cost which prevent the use of separate motors for each machine.

The next group are the carding room machines. These machines require about $\frac{3}{4}$ of a H.P. per machine, or about 8 B.H.P. for ten machines. Their speed varies from 160 to 180 revolutions per minute, and the load is a fairly steady one. Separate driving has been tried, but the cost is prohibitive, and it is now usual to group the machines and connect them through shafting running at a speed of 500 to 600 revolutions per minute direct coupled to a motor, or, at most, connected to it through single spur gearing.

The intermediate machines come next. These prepare the cotton for spinning. They generally contain from 180 to 200 spindles, and require about 3 B.H.P., the driving shaft running at about 300 to 400 revolutions per minute. The speed, of course, varies with the work, and for any particular count is a constant. It is very important that a given speed shall not be exceeded, as any undue strain causes breakages. Here again judicious grouping arrangements with overhead motors and comparatively short lengths of light shafting running at high speeds are advisable. Frequent stops are necessary and are obtained as at present by shifting the machine belt from the fast to the loose pulley.

The actual spinning is either done on mule or ring spinning machines. The mule machine is the older form, and for some classes of work it is still the favourite, though a mill usually contains both types.

The mule machines form a very variable load, and for this reason are always run in groups. The machines are about 130 ft. long, contain 1,300 to 1,400 spindles, and require an average of about 12 B.H.P. to drive them. In a complete draw of a self-acting mule machine lasting fifteen seconds, the power required may vary from 30 B.H.P. as

a maximum for a second or two to about 2 or 3 B.H.P. for the greater part of the time. The machine during this period starts from rest, attains its maximum speed of about 7,500 revolutions per minute, and again comes to rest. One of the operators controls the speed by moving the machine belt to and from the fast and loose pulley. In order to equalise the load it is usual to group the machines first in pairs, and then, through transverse shafting, to run six or eight pairs of machines from a 150 to 200 B.H.P. motor.

This plan provides plenty of power as a reserve, for it rarely happens that all the machines require their maximum power at exactly the same time.

Ring spinning machines are preferred for certain classes of work, and are usually operated by female labour. They are about 45 to 50 ft. long, and carry 400 to 500 spindles. The speed at which they run varies with the class of work between 650 and 1,000 revolutions per minute, and the spindles per horse-power also vary between about 120 spindles for 700 revolutions per minute to 60 spindles for 1,000 revolutions per minute. An ordinary speed is about 800 revolutions per minute when the number of spindles per horse-power is about 90, and the horse-power required per machine is about 5 B.H.P.

There has been a great deal of discussion as to the advantage of direct or group driving for these machines, and though there are several successful instances of group driving in this country, the use of separate motors either for each machine or pair of machines is becoming general. Thus at the Acme Mills, Pendlebury, the British Thomson-Houston Co. use a 150 B.H.P. motor bolted to the ceiling and direct coupled to the line shaft. This drives the ring frames through ropes. In other cases, however, the same firm have adopted separate driving.

Great care has to be taken both with ring spinning frames and looms in applying the direct drive of the electric motor, since the slightest sudden tension on the thread is likely to

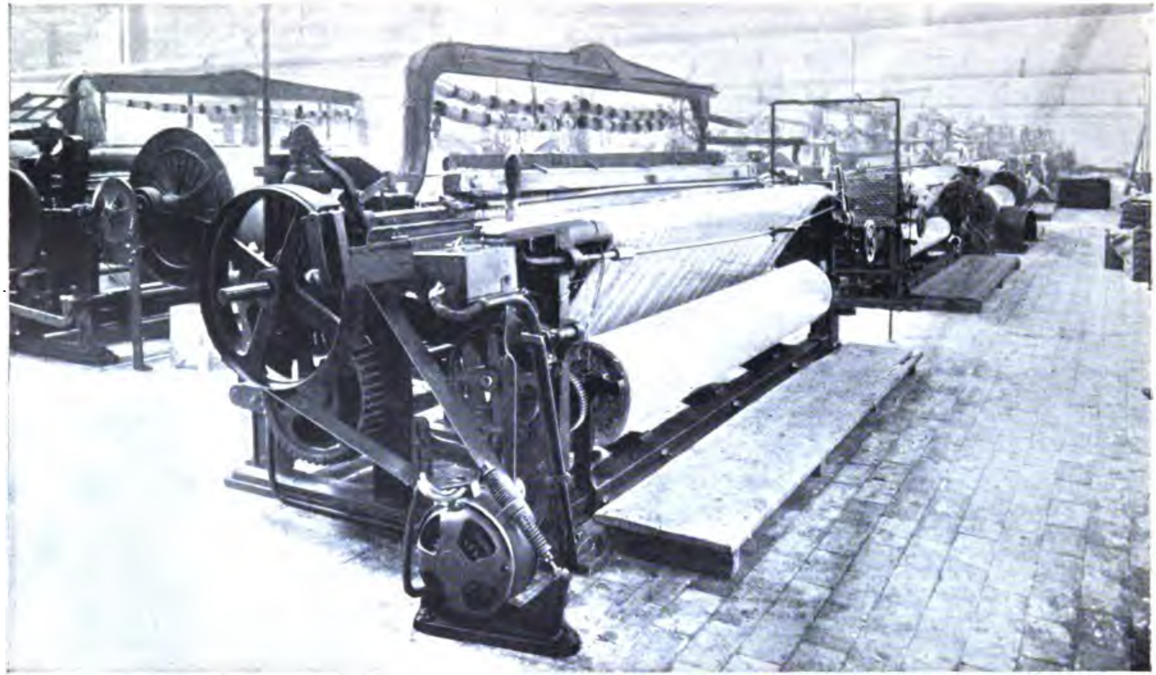

Fig. 57.—Induction Motor driving Jute Loom through Belting.

cause breakage of some of the strands. Messrs Siemens have devoted a great deal of attention to this matter, and have developed three arrangements for the purpose.

The first is a short belt drive with a spring belt tightener; this is shown attached to a loom in Fig. 57. It is the cheapest of the three arrangements, and is satisfactory for ordinary classes of work.

Fig. 58.—Induction Motor fitted for driving Ring Frame or Loom through Friction Coupling.

In the second method, which is illustrated in Figs. 58 and 59, the motor is bolted to a cast-iron frame, and the motor axle has a raw-hide or gun-metal pinion keyed to it, which gears into the toothed rim of the slipping coupling, the inner portion of which is rigidly fixed to the loom or spinning frame shaft. The two are connected through a friction band, which can be adjusted by the spring to any tension. Should any excessive load occur, or should the loom or frame be stopped suddenly at any time, the tension on the

band is relaxed, the band will slip and allow the motor to gradually stop without moving the loom or frame or spoiling the fabric and breaking the threads. In Fig. 59 the same arrangement is shown fitted to a loom.

There is a third arrangement in which a centrifugal coupling is used in place of the friction band, which cuts in when the motor reaches about 90 per cent. of its normal speed. It is stated that as in this case the motor always starts light, it may be of smaller size than if it had to start the loom or machine up from rest, while the cutting in is at the same time free from shock.

The position of the motor in the frame is adjustable to permit of the use of different sized pulley wheels, and so allow with squirrel cage induction type motors a choice of speeds for various classes of work.

With ring spinning frames a cycle of operations takes about fifteen minutes, and if it is possible to vary the motor speed to suit the successive stages of operation, the quality and quantity of the thread can be improved. With the usual mechanical drive the speed of the machine is suited to the count of the thread being made by altering the pulleys, while the regular speed of the machine is limited by the number of breaks of the thread.

When separate electric motors were used, efforts were at once made to use variable speed motors in order to take advantage of the maximum speeds permissible during the various stages of the run.

Direct current motors have been tried with some success, but direct currents are seldom obtainable in a textile mill, and to convert from alternating to direct currents introduces complications and additional machinery it is best to avoid.

Three-phase induction motors of the slip ring type with variable resistance in the rotor circuits are sometimes employed. This is uneconomical electrically and inconvenient practically, as the regulating resistances get hot and special precautions have to be taken to dissipate the heat thus produced.

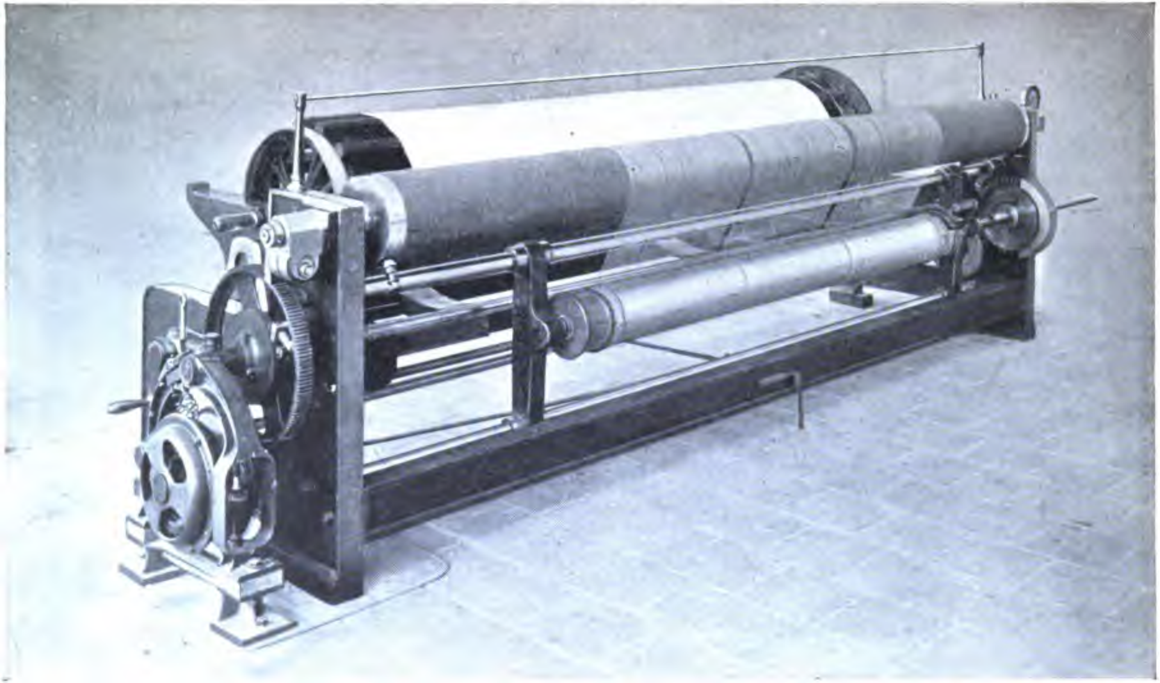

Fig. 59.—Induction Motor driving Loom through Spur Gearing.

Fortunately the single-phase commutator repulsion motor admirably meets the requirements. As mentioned in Chapter II. (page 54) this class of motor has at low periodicities met with much success for traction work. Both Messrs Siemens and Messrs Brown, Boveri, & Co. have overcome the troubles which hitherto have prevented its use on 50 ~ circuits and have developed sizes which are specially intended for ring spinning frames. In appearance, these motors resemble ordinary direct current machines. Messrs Brown, Boveri have standardised an 8 B.H.P. machine running at about 900 revolutions per minute. These motors have a high starting effort—about four times full load torque—so that the frames are very quickly brought up to full speed. The speed can also be varied without introducing resistances, by simply moving the brushes on the commutator. This can be arranged to be done automatically by the movement of a bar which rests on the cop of yarn and varies the speed of the motor, so that the tension on the yarn as it leaves the nip of the roller is maintained constant whatever the amount of yarn on the cop. By thus keeping the tension on the yarn constant, the output of frames have been increased up to 15 per cent., with a better quality product.

If the general supply to the mill is on the three-phase system, these motors may be placed—balanced as far as possible—on the separate phases.

The extent to which variable speeds will affect the output of ring spinning frames is shown by the following experiment which was made by Messrs Brown, Boveri, & Co. on a machine having a normal speed of 650 revolutions per minute. They found it was possible to divide up the spinning time as follows without any increase in the number of breaks:—

Starting the motor .	0-550	revs. per min.	3-5 seconds.
Starting period . .	550	,,	2 minutes.
Main spinning period	785	,,	10-12 minutes.

Finishing period 785-600 revs. per min. 2 minutes.
Stopping the motor 600-0 „ about 5 seconds.

The average speed of the motor during the whole spinning period was about 730 revolutions per minute, an increase of about 11 per cent. on the rated speed of the machine for that particular class of work.

General experience confirms the conclusion that it is possible to considerably increase the average speed, and therefore the output, of the machine without increasing the number of breakages of the thread.

In the weaving sheds we find various classes of winding machinery in addition to the looms.

These are generally arranged for group driving, a motor bolted to the ceiling driving through belting several machines. The looms present an interesting problem. They vary in size, and the power required varies not only with the size but also with the class of work they are doing. The smaller sizes only require about $\frac{1}{3}$ H.P., and the larger ones $1\frac{1}{2}$ to 2 H.P.

Messrs Siemens have got out a complete range of three-phase motors specially for this class of work, particulars of which are worth noting, as they show how compact small motors are:—

Output.	Motors with Starting Torque equal to Twice Normal Running Torque.		Motors with Starting Torque equal to Three Times Normal Running Torque.	
B.H.P.	Revolutions per Minute, 50 ~.	Net Weight.	Revolutions per Minute, 50 ~.	Net Weight.
		lbs.		lbs.
·25	900	62	910	62
·33	910	71	930	71
·50	920	78	940	78
·75	930	93	945	93
1·00	940	110	950	110
1·50	940	135	960	135
2·00	950	165	960	165

Fig. 60.—Weaving Shed at Heasandford Mill, Burnley, showing Group Driving from Overhead Motors.

There is no doubt that for high-class and delicate work this system of separate drive has many advantages. At the same time it is somewhat expensive in first cost, and manufacturers will probably in many cases decide that for ordinary work group driving will meet their requirements at a lower first cost.

A good example of group driving is shown in Fig. 60, which represents one of the weaving sheds at the Heasandford Mills, Burnley. This was carried out by Messrs Mather & Platt. Here, in the weaving shed they have twenty-three lines of shafting twenty-one of which each drive a double row of thirty-seven looms. Each line of shafting is driven by a 25 B.H.P. motor through spur gearing consisting of raw-hide pinions on the motor axle gearing into cast-iron gear wheels on the countershaft. The two end shafts only drive single rows of looms and have only 14 B.H.P. motors. There are thus 1,628 looms and a total of 553 rated H.P., or an average of about three looms per H.P. The motors are of the squirrel cage type and the starting switches are placed on the wall directly under their respective motors.

In the dyeing and finishing sheds the conditions are quite different. The machines used in the various processes are individually of a much larger size, and independent control of speed through a wide range is in most cases essential. Here direct current motors are very suitable, and are often employed, the arrangements and methods of control being similar to those used in connection with printing machinery.

Cost of Working.

The question of cost considered in regard both to capital outlay and cost of maintenance is all-important. It is difficult to give details of the cost of fitting mills for mechanical driving since the conditions vary in every case, but an average allowance of 2·9s. per spindle in a 100,000

spindle mill for the provision of boilers, main engine, the necessary buildings, the rope race, and the main and countershafting is not an excessive amount. This means an outlay of £14,500 on a mill of this size where both mule and ring frame spinning is carried on.

The main engine would be capable of indicating up to 1,600 I.H.P., the load under ordinary conditions, as ascertained by indicating the engine, being about 1,450 I.H.P. An indicator diagram of a mill of this size taken when no work was going on gave 550 I.H.P. as the light load loss so that the approximate power used in the machines themselves was 900 I.H.P.

The usual factory hours per week are fifty-six, and the mill runs, excluding holidays, say fifty weeks per year, so that the annual working hours may be taken as 2,800.

The following would be the approximate annual cost of working for such a mill, the figures including the wages of a man to examine and oil the shafting bearings in the various parts of the mill, and the oil used for this purpose:—

FUEL, at 2 lbs. per I.H.P. hour for working and an allowance of 6 tons per week for banking fires — Tons.

$$= \frac{1{,}450 \times 2 \text{ lbs.} \times 2{,}800 \text{ hours}}{2{,}240} = 3{,}625$$

Allowance for banking fires $= 6 \text{ tons} \times \text{fifty weeks} =$ 300

3,925

	£	s.	d.
3,925 tons of coal at 9s. per ton - -	£1,766	5	0
ALLOWANCE FOR OIL, WASTE, WATER, AND STORES, condensing water supplied from mill pond, say in all average of £3. 10s. per week - - - - - - -	175	0	0
Carried forward - -	£1,941	5	0

Brought forward - -			£1,941 5 0
LABOUR—			
One engineer -	£3 0 0	per week	
One fitter-driver -	1 15 0	„	
One oiler - -	1 5 0	„	
Two stokers at 25s. -	2 10 0	„	
Fifty weeks at	£8 10 0	„	425 0 0
ALLOWANCE FOR REPAIRS, say at rate of—			
2 per cent. on buildings, say £2,000 - - - -	£40		
3 per cent. on balance, say £12,500	375		415 0 0
ALLOWANCE FOR INTEREST AND DEPRECIATION ON CAPITAL OUTLAY at rate of 10 per cent. per annum on £14,500 - -			1,450 0 0
Annual cost -			£4,231 5 0

The approximate cost of equipping a works' generating plant with one turbo-alternator capable of developing 800 KW. as a continuous normal load, which would be practically the electrical equivalent of the above plant, is £11,000 (see page 171).

To make the case comparable with the above mechanical drive installation, we must add the cost of the cables to the various floors, the motors with their starting gear, and what shafting and accessories are necessary for driving the various machines. This can, of course, only be taken at an average figure, but allowing for a certain proportion of the ring frames to be driven separately, the sum of £3,750 should cover the outlay.

The total cost of the electric drive applied to a new mill,

if one generating unit is provided, may be taken as £11,000 + £3,750, or a total of £14,750, while if it is felt necessary to provide duplicate generating plant, the cost will be £13,000 + £3,750, or a total of £16,750.

It is difficult to estimate the average load, but even assuming that the motor and shafting losses equal the losses under the mechanical drive, which is unlikely, the average load will not exceed 800 KW., making the weekly output 44,800 units (see page 171), and the annual output for fifty working weeks per year $44{,}800 \times 50 = 2{,}240{,}000$ units.

The average cost per unit generated at this output and under these conditions has been shown on page 172 to be 0·417d. per unit with one generating unit and on page 175 to be 0·470d. per unit if spare plant is installed.

The total annual cost of the electric drive, including attendance, repairs, and interest and depreciation charges on the capital cost of the motors and accessories, will be:—

(*a*.) WITH ONE GENERATING UNIT.

ENERGY, 2,240,000 units generated at 0·417d. per unit - - -	£3,892	0	0
ALLOWANCE FOR OIL AND WASTE for motors and countershaft bearings -	25	0	0
ALLOWANCE FOR ATTENDANCE, say one man (one-third time) at £1. 5s. per week fifty weeks per annum - -	20	16	8
ALLOWANCE FOR REPAIRS at rate of 3 per cent. on £3,750 - - -	112	10	0
ALLOWANCE FOR INTEREST AND DEPRECIATION at rate of 10 per cent. per annum on £3,750 - - -	375	0	0
Annual cost -	£4,425	6	8

(*b*.) WITH TWO GENERATING UNITS (ONE SPARE).

ENERGY, 2,240,000 units generated at 0·470d. per unit - - - -	£4,386	13	4
ALLOWANCE FOR OIL, WASTE, &c., as above - - - - - - -	25	0	0
ALLOWANCE FOR ATTENDANCE, as above	20	16	8
ALLOWANCE FOR REPAIRS, as above -	112	10	0
ALLOWANCE FOR INTEREST AND DEPRECIATION, as above - - - -	375	0	0
Annual cost -	£4,920	0	0

These figures show that the approximate relative annual costs of working with the mechanical and electrical drive under similar conditions, that is, using one generating set, would be:—

Mechanical drive - - - - -	£4,231	5	0
Electrical drive - - - - - -	4,425	6	8

showing a saving in favour of the mechanical drive of £194. 1s. 8d., or about 4½ per cent.

If it is deemed necessary to divide the electrical generating plant into two sets, one of which can be used as spare, the comparison becomes:—

Mechanical drive - - - - -	£4,231	5	0
Electrical drive - - - - -	4,920	0	0

showing a saving in favour of the mechanical drive of £688. 15s. 0d., or about 16¼ per cent.

So far, therefore, as actual cost of working is concerned, the mechanical drive has the advantage. The figures show that it is in the direction of improved quality and the increased

quantity of the finished product that the justification for any change of method of working must be found. It is very probable that, as to a certain extent separate driving is allowed for in the above capital outlay of £3,750, the number of units required would be lessened, and the total cost for electric energy reduced.

When it is remembered that the cost of power in a textile mill is only about 3 to 5 per cent. of the total cost of manufacture, it will be realised that an improvement in quality and quantity of the finished product will soon more than counterbalance the small increase in the cost of producing power, and will exert a very favourable influence on the annual balance-sheet.

The ease with which electric energy can not only be measured but, by the use of recording instruments, can be automatically registered is of great use in maintaining a high rate of efficiency in the working of the mill. Comparisons of records taken on the same sets of machines at different times will do a great deal to locate waste of power, and enable faults to be remedied before they have had time to seriously affect the cost of working.

The question of the purchase of energy from an outside source, in place of generating it on the works, has already been partly dealt with (see page 199). It was there shown that under the stated conditions, namely, an average load of 800 KW. and a maximum load of 850 KW., the average price per unit on a tariff of £4 per KW. of maximum demand plus 0·25d. per unit would be 0·60d. per unit as compared with 0·417d. for the self-contained plant with one generating unit, or 0·470d. with the two generating sets.

For a load of this character it would, however, in all probability be possible to obtain a rate of 0·50d. per unit, or even lower, especially when coal is taken at the price of 9s. per ton, as in these calculations.

The total cost of working if this is the case will be :—

ELECTRIC ENERGY, 2,240,000 units purchased at 0·50d. per unit - - - -	£4,666	13	4
OTHER CHARGES AS BEFORE (page 232)—			
Oil, waste, &c. - - - - - -	25	0	0
Attendance - - - - - -	20	16	8
Repair allowance - - - - -	112	10	0
Interest and depreciation allowance -	375	0	0
	£5,200	0	0
COST WITH WORKS GENERATING PLANT WITH ONE SET - - - - - - - -	4,425	6	8
Difference - -	£774	13	4
It must, however, be remembered that if the energy is purchased, the £11,000 which would have been spent on generating plant can be invested in directly productive machinery, and it only needs this sum to earn a profit of 7 per cent. per annum to equalise, even so far as cost is concerned, purchased, as against generated energy on the conditions specified - - - - - - -	£770	0	0

Each one-hundredth of a penny (0·01d.) by which the price of electric energy was reduced, would make £93. 6s. 8d. difference to the cost of purchasing power, if the same number of units were required. Furthermore, the manufacturer would have the whole of the power station spare plant as an insurance against failure of supply, extensions could be easily arranged, and any reduction in the demand due to increased works efficiency would be directly reflected in the charge made by the power company for energy supplied.

As power companies are usually willing that an amount not exceeding 20 per cent. of the total energy taken may be

used for lighting purposes, there is a further advantage in thus securing the lighting units at the same rate as the power supply. This ensures a lighting supply at all times, without reference as to whether the main engine was running or not, and, if the mill were previously lit with gas, would show a considerable economy.

Against these savings must, however, be placed the extra cost of providing steam for heating the mill in winter, and when necessary humidifying the air used in some parts of the mill. The steam for this purpose is often obtained from the works steam plant, and if this is dispensed with, a separate low pressure boiler must be provided, and some one detailed to give it the necessary attention.

CHAPTER XI.

ELECTRIC POWER IN PRINTING WORKS.

The Special Needs of Printing Machinery—How a Direct Current Motor meets these Requirements—Alternative Methods of Driving—Group Driving and Separate Motors—Improved Output with Electric Drive—Automatic Controllers for Flat Bed Presses—Newspaper Printing—Various Systems of Control in Use.

THERE are few industries in which the advantages of the electric drive have been more generally appreciated than in printing establishments. It is now used by many of the leading firms, and its adoption by others is largely a question of time and convenience.

This is not to be wondered at when one remembers that the great need of printing machinery is varying speed under complete control. When making ready it must be possible to move the paper "inch by inch" as well as to run slowly while taking trial sheets, and then the machine must be worked at the highest speed permitted by the class of work being done and the paper employed. The start should take place without jerking, and the acceleration should be uniform, and the machine must be capable of being stopped immediately should it be necessary to do so. In small works the load factor is necessarily low, there are only a few machines, and as setting up the type and making ready take up far longer time than actually printing off, the time during which full power is required is comparatively short.

The direct current motor supplied with power from an outside source fulfils the above conditions better than any other prime mover. It is compact, and may if desired be applied to each individual machine, making it a self-con-

tained unit taking power only during the period of work, and an amount practically proportional to the work being done. The electric motor is reliable, in its modern forms it rarely breaks down, and it requires practically no attention.

The shunt wound motor fulfils many of the requirements of printing machinery and is generally employed, except for flat bed presses where compound wound motors are preferable. This is due to the fluctuation of the load caused by the periodical reversal of direction of movement of the bed of the machine. The series coils strengthen the magnetic field at the moment of reversal and so increase the torque and the rate of acceleration. By thus decreasing the range of current which would otherwise take place at the moment of reversal, a saving of energy, often amounting to 5 to 10 per cent. over shunt wound motors, is obtained, while the rate of working is not affected.

Shunt wound motors under normal conditions run at practically a constant speed, while they are capable of being easily controlled throughout a very wide range of speed. This is often done by choosing a motor to run at its normal speed when driving the machine to which it is connected at its standard speed. Regulation from this speed downwards is usually done by inserting resistance in the armature circuit, and above this speed by weakening the field by inserting resistance in the shunt circuit. It should be remembered that while regulation of speed by varying the field strength is convenient and economical, its wide application means the employment of a large motor for the work, and consequently increases the capital outlay. The range of control and the number of steps into which it is divided are matters of arrangement, they can be made to suit any requirements, 15 to 20 per cent. increase of speed in this way is very usual.

With larger machines, when separate driving is adopted, overhead shafting is entirely dispensed with. This not only removes a great source of energy loss, but what is very

important, makes the shop lighter and brighter, and so conduces to better work. If necessary it is easy with the electric motor to arrange to short circuit the motor on itself in case of an emergency, and so provide a very effective brake which will enable the operator to stop the machine at once if necessary.

It is also possible to arrange stops and switches on different parts of either rotary or flat bed presses from which the motor may be completely controlled.

The alternative to an electric motor is either a steam or gas engine driving the machines through shafting with belts down to the various machine pulleys, or a steam engine independently coupled to a rotary press. A belt drive to a rotary press will give trouble unless the inevitable jar on starting is toned down through some form of friction clutch, as the jerks due to throwing the paper on and off break the paper. It is the possibility of an easy start and complete control which makes electric driving so popular in the printing shop.

For flat bed presses, where this question does not arise, fast and loose pulleys and striking gear are fitted to each machine, and the small movements necessary during the making ready periods are obtained by suddenly moving the belt on and off the main pulley. The pulley ratios are arranged for the best working speed of the machines, and sometimes step or cone pulleys allow several speeds to be used, but the speed adjustments have to be made while the machine is stopped.

In addition to the losses which the shafting and countershafting inevitably cause, especially in large works, there are the long periods to be considered during which only one or two of the machines are working. As already explained, gas or steam engines running lightly loaded are very uneconomical, and the expense of thus keeping the machinery ready to run is considerable.

It is sometimes possible to subdivide the load, and by

using two or three gas engines to reduce the amount of idle shafting running, but at best the losses are heavy, the large amount of overhead shafting is a disadvantage, the cost of maintenance and repairs is considerable, and the extra noise of the shafting and engines is an annoyance.

It will be evident from the figures given in earlier chapters that the electric drive will certainly be cheaper than its competitors, if power supplied as direct current can be purchased at a reasonable rate—say at one penny per B.O.T. unit—from an outside source. If the price per unit is above this figure, or if the energy has to be generated on the works, it is necessary to consider the conditions of each case before coming to a definite decision as to relative cost. The saving is increased in the case of purchased energy by the many occasions on which it is necessary to run one or two machines overtime in printing works, while, if care is taken in grouping the auxiliary machines to class together those which are likely to be required for overtime work, considerable further economies can be secured.

Owing to the need for speed control within such wide limits direct currents are most suitable for use in printing works. There are several ways of controlling the speed of induction type alternating current motors, but they are not economical, and under ordinary circumstances should be avoided. There is, however, every probability that single phase commutator type motors will soon be adapted for printers' requirements, and so any disadvantage of an alternating current supply will be removed.

The machines used by printers vary considerably both in size and in character. The small machines such as cutters, rulers, and binders may only need from $\frac{1}{3}$ to 1 H.P.; an ordinary flat-bed press rarely requires more than 5 to 6 H.P.; while some of the large rotary presses used for printing newspapers may need 50, or even 80 H.P. to drive them.

There is a tendency on the part of some printers to use electric motors for the large machines which require separate

motors, but to group the auxiliaries together and employ a gas engine to drive them. If electric energy can be purchased at a reasonable rate, there are few cases in which it would not prove most economical to rearrange these small machines into groups and employ electric motors. The power required per machine rarely exceeds 1 H.P., and six or seven machines could usually be arranged with a reasonable amount of shafting, when a 4½ or 5 B.H.P. motor would be large enough to drive it. As only constant speed would be required, only a starting resistance and switch is needed. The motor chosen should be of the enclosed protected type and shunt wound, and it may be bolted to the wall or ceiling, thus avoiding taking up valuable floor space.

The printing presses themselves, and often even the smaller platen machines, are usually driven from separate motors. This is done for two reasons, one the intermittent character of their running time, and the other the advantage of having separate speed control. When each machine is a self-contained unit it can be worked at the maximum output permissible for that particular machine, and not at the average speed determined by the speed of the shafting. The effect of this change is shown by the fact that in a number of instances the output of the works has increased 20 to 25 per cent. as the result of the change from gas engine to electric driving.

In printing works it is specially important that only the best types of starting and regulating switches and resistances should be used, and that they should be amply large enough for their work so that they do not become overheated. For constant speed motors any of the starters described in Chapter III. may be used, and in some instances controllers of the drum type with ample provision for shunt regulation are employed for the speed control of those motors which drive the separate machines.

In many cases, however, particularly with flat bed presses,

something more is required. It is necessary during the preparing process that the attention of the operators should be concentrated on the machines, and that it should be possible to start, stop, or "inch" the machine without moving away from the "formes"; moreover, this control must be certain, as any failure to act might result in a serious accident to the operator. It should also be impossible for any one to start a machine without the knowledge and consent of the operator. It is therefore becoming more general to use in printing work some form of electrically controlled starter which will allow the operator to start the machine at its slowest speed as well as to stop it immediately without moving from his position on the machine. The whole apparatus must be so strongly made that constant operation during the preparing process will not injure it, and it should be so designed that, on the stoppage of the motor from any cause, the switch arm will return to the starting position with all resistance in circuit.

A successful automatic starter of this type is that designed by Mr Frank Broadbent which is made by the Adams Manufacturing Co. Ltd. This is illustrated in Fig. 61 and is typical of this form of apparatus. The main switch is shown at the top right hand of the slate base. Underneath is a switch arm controlled by the solenoid plunger which regulates the resistance in circuit with the motor. The dashpot prevents this arm being moved too quickly. The solenoid is energised from the power mains by a separate circuit to that operating the motor and is taken to the several points of remote control on the machine. As the current is very small this control wire is also of small size. At these control points small switches, usually of the push-button pattern, are mounted on the machine. Closing any one of these switches will energise the solenoid and start the motor.

For stopping the motor another circuit is taken from the terminals of the holding down coil, to the various control

Fig. 61.—The Broadbent Automatic Motor Control Switch for Printing Machines.

points and there connected to separate push-button switches. Pressing any one of these, short circuits and demagnetises the holding on coil, releases the main switch, stops the motor, and the fall of the solenoid core by gravity causes the switch arm to return to its starting position.

"Inching" the machine is effected by closing first one of the starting push-buttons and then one of the stopping ones, and can be carried out to any extent without moving away from the machine.

The closing of any of the starting push-button switches on starting the motor, energises the solenoid which attracts the solenoid core and lifts the lower switch, thus inserting all resistance in the armature circuit. When this nears its final position the pointer, fixed at right angles to the switch arm, presses against the main switch and moves it towards the holding on coil, at the same time completing the field circuit of the motor as soon as the main switch arm passes over the first contact. The solenoid remains energised until the fields of the motor have had time to excite and the holding down coil is able to keep the main switch in position. The passage of the main switch over the contact pieces towards the holding on coil completes the armature circuit and starts the motor. The arm connected to the main switch now moves the spring contact shown at the top of the switch and breaks the solenoid circuit. The plunger now begins to fall but is prevented from moving too fast by the dashpot. In its fall it gradually cuts out of circuit the motor resistance and allows the motor

Fig. 62.—Kohler Standard Controller for Flat Bed Press.

to reach its normal speed. Any further adjustment of speed by insertion of shunt resistance is done by hand, the shunt resistance being interlocked with the starting switch so that it cannot be operated until the whole of the armature resistance is cut out of circuit.

Another successful automatic starter is that illustrated in Fig. 62, and made by Messrs Kohler Brothers.

It is mounted in front of the wire resistance, and the complete controller may be placed in any convenient position on wall, post, or ceiling, right away from the press.

The entire control is automatic, and is carried out from the push-button switches. Two of these switches are usually provided, one placed at the feed board, and the other at the delivery end of the machine. These switches have four push-buttons marked respectively, "on," "off," "run," and "safe."

When the "on" button is pushed the machine starts slowly, and gradually accelerates up to full speed. Pushing the "off" button reverses the action, and the machine slowly stops. When the "stop" button is pushed the machine is stopped at once, and cannot be restarted until the "run" button has been pushed in.

A locking device is also provided which can be set for any given output per minute, so that the press cannot be worked at a faster rate without the foreman's knowledge. This is useful in ensuring uniform work.

The usual overload preventer and no-load release coils are fitted on the panel.

The principal advantages of this form of controller are the complete automatic control over all the operations of the machine, freedom from sparking contacts, and increased safety to the worker on the machine. Misuse of the controller itself is avoided, because the operator uses the push-buttons only, and does not require to touch the controller switches.

The question of what speed motor to employ for any given machine depends upon custom and circumstance.

Some people prefer medium speed motors geared either through belting or raw-hide pinions to the individual machines, whose main shafts usually run at from 100 to 120 revolutions per minute. Others prefer slow speed motors coupled direct to the machine main shafts. Both methods will give satisfactory results, the latter being the more expensive in first cost.

In newspaper work, the conditions to be met differ somewhat from those prevalent in ordinary printing shops. A rotary press taking 50 B.H.P. will turn out about 45,000 to 50,000 eight-page papers per hour. The periods of actual printing are very small, for the greater part of the time the machine being either idle or being "prepared." It is necessary to provide for even acceleration and slow starting movements, for stopping arrangements which can be relied on to act immediately, and also for working during the actual printing period at the maximum rate the paper will allow. It must also be possible to move the plates through fractional parts of an inch while setting up, and whatever the variation in speed of the machine, to avoid any jar which would break the paper. There are a number of methods of control in successful use in the different newspaper offices, the principal ones being outlined as follows:—

A. The Holmes-Clatworthy system, which has been installed by Messrs J. H. Holmes & Co. in over forty large newspaper printing offices, including *The Times*, *The Daily Mail*, and *The Daily Chronicle*. In this system two motors are provided, a large one capable of doing the whole of the work, and a smaller high speed motor placed at right angles to the main motor, and connected to its axle through a worm gear and clutch. When starting and running at slow speeds, the smaller motor alone is used. As the controller handle is moved on, the current is switched on the larger motor circuit and off the smaller one, the clutch is thrown out so that the smaller motor is disconnected, and further regulation of speed is obtained by introducing resistance into the shunt

circuit of the larger motor. In this way, a satisfactory control throughout a wide range of speed is obtained.

B. The Scott system, with which the firm of Laurence, Scott, & Co. Ltd. is associated. This is used in *The Standard*, *The Daily News*, *The Star*, *The Birmingham Daily Post*, and other offices, and is noteworthy for its simplicity. Only one motor is used direct coupled to the press shafting, and all regulation is obtained by means of resistances placed in its shunt circuit. In a standard 40 B.H.P. equipment, driving a Hoe three-roll press at 200 revolutions per minute, and printing 24,000 twelve-page copies per hour, there are thirty-five steps on the controller. The first steps start the motor at very low speeds, 4 or 5 revolutions per minute, and this may be gradually accelerated up to 250 revolutions per minute. One advantage of this method is that the rate of acceleration is steady throughout the whole range, while another is that the speed at any particular step of the controller is the same whatever the load. The operators find this a very useful feature, and though the motor is large and expensive at the outset, reports as to its reliability in actual use are very satisfactory.

C. The Bergmann-Burke system of the Bergmann Co. of Berlin, for whom Marples, Leach, & Co. Ltd. are the British agents, is used by *The Standard*, *The Daily News*, *The Edinburgh Evening News*, *The Northern Daily Telegraph*, and others with satisfactory results. Two motors are employed mounted on the same shaft, one series and the other shunt wound. Variations of speed from one-twentieth of full speed up to full speed are obtained by varying the connections of the two motors to the line, the lower speed being found slow enough for use when preparing the "formes." The motor armatures are first placed in series, and later, as the speed increases, in parallel with each other. Variations in the strength of the field magnets and in resistance placed in the armature circuits permit of as fine a regulation of speed as desired. Though somewhat

costly and apparently complicated, all the changes take place on successive movements of one controller handle.

D. The Bullock system is also largely used, amongst

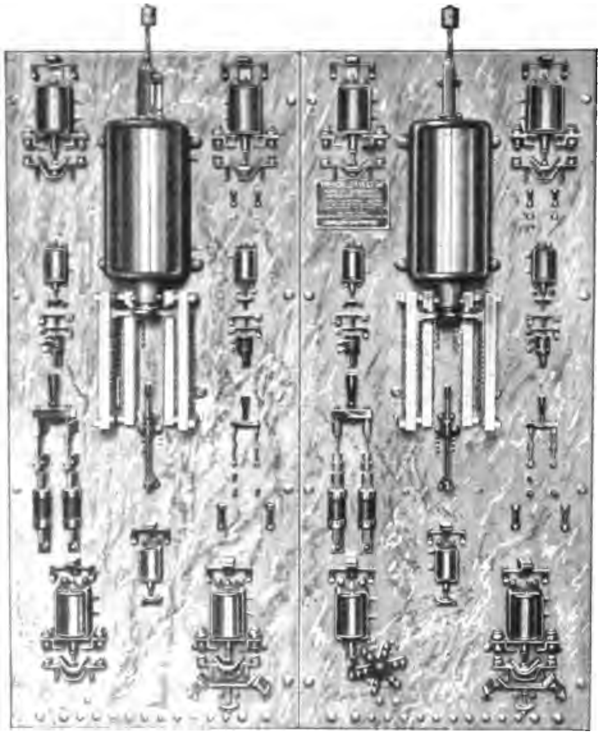

Fig. 63.—Kohler Four-Motor Controller for Newspaper Rotary Presses.

others in *The Daily Mail* and *The Daily Express* offices. It consists of a large motor capable of doing the whole work, and a small motor generator placed at starting in series with the main motor. This motor generator takes a small current

from the line, which it transforms to low pressure and correspondingly larger current, and supplies this to the main motor. The motor then acts as if it were working on a low voltage circuit and starts at a slow speed. Control is at first obtained by increasing the speed of the small motor, and then, by cutting this out of circuit and using only the large motor, placing resistance first in the armature circuit, varying the speed by cutting this out, the higher speed control being obtained in the usual way by weakening the motor field.

The Kohler system has made considerable headway during the past year or two. It was used in printing *The Daily Mail* at the Franco-British Exhibition, and aroused a great deal of interest. The press there shown was capable of printing 100,000 eight-page papers per hour, and the equipment consisted of two 60 H.P. and two 10 H.P. motors, with the standard "Kohler" four-motor controller. Each of the main 60 H.P. motors were coupled direct to the press-shaft of the machine and an auxiliary 10 H.P. motor was connected to this press shaft through a worm-wheel and free wheel.

Fig. 64.—Push-Button Operating Switch, for Kohler Printing Press Controller.

The auxiliary motor was used for operating at slow speed when dressing the press and leading in the paper web. The main motor took up the load and overran the small motor when operating at printing speed. Fig. 63 gives a general view of the controller used with this press, and Fig. 64 shows the push-button operating switch of which sixteen were placed in convenient positions on the machine.

The principal features of the "Kohler" system of control are:—

While putting on blankets or plates the cylinder can be brought to any desired point, and moved by eighths of an

inch if desired. The speed of the plate cylinders can be varied from ten revolutions per minute through many intermediate speeds to the maximum speed. There are five buttons on each push-button switch, marked respectively, "on," "stop," "off," "run," "safe." While a press is being made up, and a pressman is working on any part of the same, he can push the "safe" button in the switch nearest him and it will be impossible for any one to start the press until he has pushed the "run" button and so released the stop imposed by the "safe" button. To start the motor the "run" button is first pushed home, and then the "on" button, when the press can gradually be run up to full speed without jar or jerk, or can be limited at any moment by pushing the "safe" button. To stop the motor gradually, the "off" button is pressed, and to stop quickly, the "stop" button is used.

It is thus possible to entirely control the working of the press and to fix any limited speed desired from any of the control points. This is a great advantage, the even motion and freedom from jerks not only increasing the output, but preventing the breaks of paper which are so annoying when running off the sheets.

The additional element of safety to workers is also a great gain. The press is first started up on the small 10 H.P. motor through the worm gearing by pressing the "run" button which releases the plunger seen in the centre of each starting panel (Fig. 63). This slowly descends, cutting out the starting resistance of the small motor. Its descent can at any time be arrested by pressing the "safe" button. If allowed to descend, the small motor reaches its maximum speed, and the large 60 H.P. motor takes up the load, leaving the small motor free, until, on the motor slowing down, it takes up the load if only small movements or slow motion of the press is required.

In this way the use of large resistances for the 60 H.P. motor running at slow speeds is dispensed with, while

perfect control is maintained from maximum down to the lowest speeds.

The other solenoids on the board enable the two pairs of motors to be worked separately or in parallel. The main switches shown at the bottom right-hand corners of the panels are controlled by the "stop" button and the overload and no-voltage release. When the main switches open, they short circuit the motors at the same time, and by the braking action thus introduced bring the machine to rest in a very few seconds.

This method of control is used in the printing offices of *The Morning Post*, *The Manchester Evening Chronicle*, and is now being adopted by *The Times*, *The Daily Mail*, and *The Daily Mirror*, as well as some important Continental papers.

CHAPTER XII.

THE USE OF ELECTRIC POWER IN ENGINEERING WORKSHOPS.

Need for Careful Arrangement of Electric Motors in Engineering Workshops to Secure Economy—How to Reduce Shafting Losses—Methods of Transmitting Power from Motor to Machine Tool—How Motors have Affected Machine Tool Design—Savings to be Expected from Electric Driving—Portable Tools and their Uses—Electric *versus* Compressed Air Driven Tools—Comparison of Cost—Flexible Shafts—Magnetic Drill Posts—Types of Tools.

THE use of electric motors for driving machine tools has become the rule rather than the exception, during the past few years, in all newly designed workshops. At the same time a large number of existing shops have been changed over to electric driving. Probably, however, in no other industry is the proportion of cases higher, where the motors are so arranged that the possible advantages of electric driving are to a large extent thrown away.

This is, no doubt, partly due to the fact that the works manager—while an expert in his own department of engineering work—has not the time to study the points which govern the economical application of electric driving to machine tools. He feels, however, that it is part of his duty to deal with any engineering question which may arise in the works, and he does his best, often by simply substituting a few motors for the main driving belts for the shafting in different sections of the shops. The result is, that the shafting losses are only slightly reduced, the motor losses to a large extent make up the difference, and the total power used is much the same as before.

Under these conditions the cost of electric driving often exceeds that of simply using gas or steam engines. In Chapter VI. it was shown that taking a favourable case of a small shop where the length of shafting was comparatively short, and the losses consequently low, the effect of dividing a 10 B.H.P. load between four motors was to keep the working cost practically the same during the day as compared with a single motor drive, while for driving a few tools overtime, the cost of the subdivided drive was less than one-half.

An engineering workshop is naturally a difficult place to drive economically, though few engineers fully realise the inefficiency of the usual arrangements. Tools are placed in convenient positions for work; shafting, countershafting, and gear wheels are added to supply the power; and it is not until changes are contemplated and tests are made by indicating the engine with the machinery working and running idle that one discovers that only from 10 to 20 per cent. of the total power supplied to the shops is doing actual work, the remainder simply representing the losses which take place between the engine and the tools. Taking an average, these losses amount to 50 per cent. of the total power supplied, one-half of which is usually expended in the top gear which is fixed for speed changing purposes above the various machine tools.

Mr W. H. Allen, in his well-known works at Bedford, has considerably reduced these losses by driving the various tools direct from the shafting, using a cone or sleeve on the shaft with a cone clutch, which puts the tool in action when wanted. An incidental advantage of this arrangement is the ease with which any particular tool can be driven by a portable motor should it be desired to work any tool overtime without running the main shafting.

The savings effected by electric driving are largely due to the reduction of the time that idle shafting is being run. The ideal method of grouping tools is to select those used

at the same time, and, as far as possible, place them together. In this way the shafting is divided into sections, some of which are constantly working nearly fully loaded, while other sections are only needed part of the time, and when the tools are not at work the motors driving these sections can be stopped altogether.

It is, however, nearly impossible to carry this out in modern workshops, for the proper sequence of operations in regard to the progress of the work through the shop makes it necessary to group the machines in such a way that the easy and economical handling of the work is made the first consideration. The cost of power in many operations is not more than 10 per cent. of the value of the finished goods, in some cases it is barely 2 per cent., while the labour and establishment charges may amount to 50 or even 70 per cent. Hence any attempt to economise power by the grouping of the machines must be done with great care and due regard to all the circumstances, as it may often prove most economical to be extravagant in the consumption of power if thereby the cost of labour can be appreciably reduced.

The number of tools which should be run from one length of shaft, and thus from one motor, depends on circumstances. Where possible, the motor should be placed in the centre of the shafting, as this plan enables the size of the shaft to be kept small.

A usual speed for shafting is about 120 revolutions per minute, though 150 and even 200 revolutions per minute are used in modern mills and workshops. These speeds permit driving through belting from motors running at from 600 to 1,000 revolutions per minute, good average speeds for medium sized motors.

The size of motor required for a number of small tools such as lathes, drillers, and slotters, varies with the class of work. Mr A. D. Williamson, as the result of a wide experience at the various works controlled by Messrs Vickers,

Sons, & Maxim, recommended an average of 10 B.H.P. in the motor for every 100 feet of shafting.

Much has been written as to the actual power required for individual machines; this is, of course, dependent upon the character of the metal, the size of the cut, and the speed of working, and unless full details are given in each case the figures are of little use. The ordinary sized lathes and tools used in brassfinishing shops take about $\frac{1}{3}$ to $\frac{2}{3}$ H.P.; for steel the power necessary is much greater.

The medium for transmitting the power from the shafting to the machine is nearly always belting; for driving from main shaft to countershaft ropes are occasionally employed, and quite recently with electric motors, chains have been tried with marked success. The special forms of chain, such as the Renold and Morse, now on the market, permit short drives, and allow ratios of as much as 6 to 1 to be successfully used. The chain speed may be as high as 1,500 ft. per minute. The gearing is comparatively noiseless, and the motor can be bolted if desired to a wall or girder near the shafting to be driven, and so avoid taking up valuable ground space. This form of gearing should not be used in dusty positions.

For large machine tools separate motor driving has many advantages, the principal one being that it permits the tool to work at its maximum output when necessary, and to be placed in a position which makes the economical handling of the work and the following of a proper sequence of operations easy and convenient, thus saving time and labour. It also allows any desired variation of speed of working without reference to the main shafting or other tools. The motor, too, is so compact that it is a comparatively easy matter to combine it in the machine design, and so render the tool a self-contained unit. It is not possible here to deal with many of the applications which have been made of the electric motor drive to particular tools. It is sufficient to point out that the general design of modern tools is being

distinctly modified by the possibility of applying the power from the electric motor just where it is required, and arranging to control the motor speed to suit the work in a manner till now impossible.

Two examples of motor-driven lathes may be given as typical of the trend of modern practice. Both lathes are made by the firm of Alfred Herbert of Coventry. In Fig. 65 one of their hexagon turret lathes is driven by a constant speed motor placed on the floor, and driving upwards through an endless laminated leather belt. The motor base is hinged, and a screw permits of the adjustment of the tension of the belt. The lathe will turn bars 2 in. in diameter, having lengths up to 30 in., the pulley running at 400 revolutions per minute, and the motor having a full load capacity of 7½ B.H.P. In this tool, adjustments of speed are made in the tool itself, so that the motor need only be large enough to give the normal output at the rated speed, and only motor starting switchgear need be provided.

In Fig. 66 we have an example of a capstan form of lathe driven by a variable speed motor. The motor is mounted on an extension of the lathe bed, and drives the lathe through spur gearing. The motor regulator is mounted on a pillar at the side of the tool with the handle convenient for the operator. In this case a direct current shunt wound motor is used, the speed being regulated within a ratio of 3 to 1 by inserting resistance in the shunt circuit of the motor. The motor must therefore be large enough to give the required output at its lowest speed. It is necessarily more expensive than the constant speed motor, but the greater convenience and the almost perfect control which the operator has over the speed of the tool, in many cases more than compensates for the increased cost. A variable speed is a necessity if it is required to maintain a constant cutting speed on work of varying diameters.

In planing machines it is possible, when separate motor

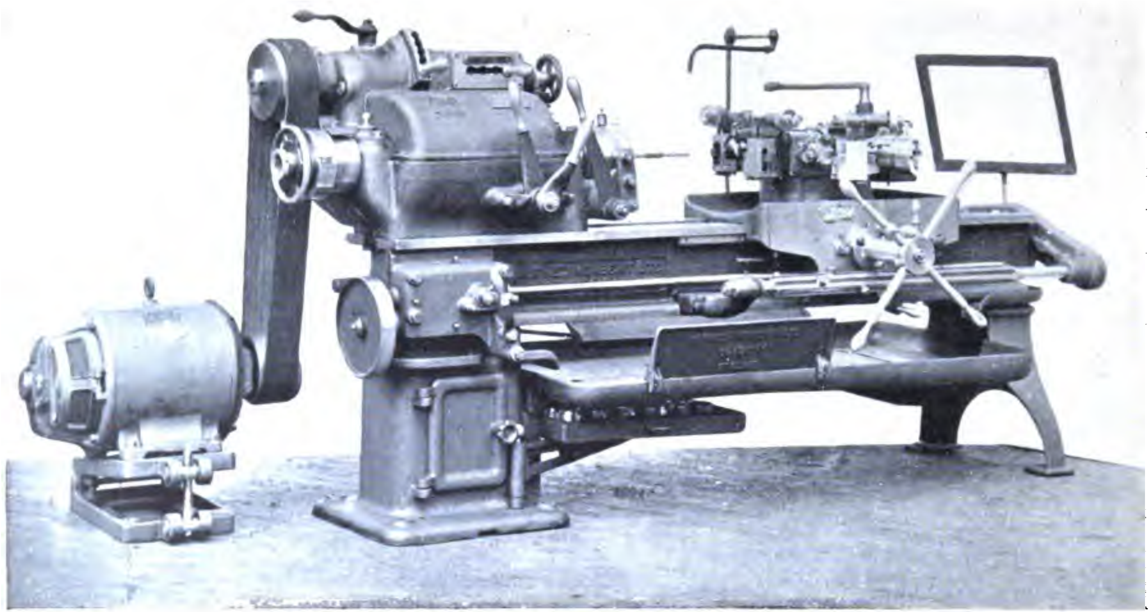

Fig. 65.—Hexagon Turret Lathe driven from Electric Motor through Belting.

R

driving is adopted, to arrange for the return to be made at a much higher speed than the forward run, thus increasing the proportion of the cutting time of the tool to the total time the tool is being worked. In fact, it is only when the practical convenience of the motor drive has been proved in daily work, that it is realised what it can do in the way of quickening up the speed of working, while at the same time maintaining the quality of the finished product.

The usual method of transmitting the power from the comparatively fast running motor to the slow running tool, when it is direct connected, is through spur gearing. These are made either with ordinary metal, raw hide, compressed cotton, or compressed paper wheels, and the gears may be either straight cut or morticed. All these may be arranged successfully, the character of the work and the permissible noise determining the method used in any particular case. Gears consisting of one metal and one raw-hide pinion are often used, while paper pinions consisting of pressed paper working surfaces held in position by metal end shields have been introduced with success, and quite recently compressed cotton gear wheels have given excellent results. With both raw-hide and paper pinions the permissible surface speed is much higher than if only metal wheels are used.

In cases where the power to be transmitted is small, and the ratio of transformation high, worm gear may be used with advantage. These gears have been improved considerably during the past few years, and there are cases where they are being used to transmit up to 150 B.H.P. with success. To get efficient results care has to be taken with the design of the rings and thrust bolts. When well made these gears last a long time, but they are expensive. Epicyclic and planetary gears are also used for machine tool drives.

The reliability, compactness, and adaptability of the electric motor is fast making it indispensable for heavy engineering work. It is being utilised for driving all classes of machines, and has, in cases where direct comparison with

older methods of working have been possible, been shown to have effected great economies. Indeed, Mr A. D. Williamson, in a paper read before the Institution of Electrical Engineers, stated that at the Barrow shipyard of Messrs Vickers, Sons, & Maxim, "the actual result of converting the works to electric driving was a saving of half the coal bill, with an increase in output of over 50 per cent."

In this paper some interesting figures were given as to the effect of the introduction of the new tool steel upon the power required for machine tools.

It was found that working at such a rate that the cutter ran for two hours without regrinding, the number of pounds of steel removed per tool is about 10 per horse-power. A lathe having 36-in. centres, with four tool posts, was found to absorb about 10 B.H.P. per tool post when cutting with this steel, and a number of these lathes, which had for the ordinary steels been fitted with 10 B.H.P. motors, were refitted with motors having a normal rating of 30 B.H.P. and an overload capacity of 40 B.H.P.

In special cases the amount of metal removed per B.H.P. may be more than double that given above; the limiting factor is the effect on the cutter, and this varies with the hardness of each particular specimen of steel.

The question of what tools should be provided with separate motors must be decided on the merits of each case. Speaking generally, the following may without hesitation be thus arranged:—

(*a.*) Tools working intermittently and taking 10 B.H.P. or over.

(*b.*) Tools requiring a wide range of speed control to give maximum output.

(*c.*) Tools taking widely varying loads in short periods of time.

Some engineers prefer to use separate motors for all machines using more than 5 B.H.P., and for special tools go down to much lower limits. Others place more reliance

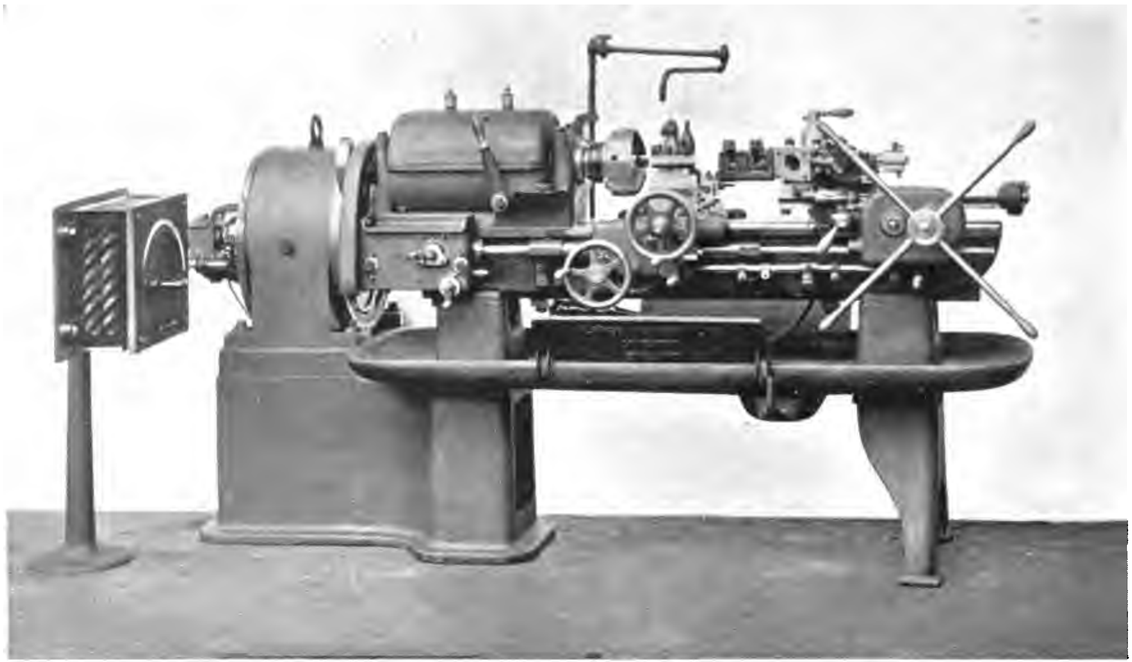

Fig. 66.—Capstan Lathe direct coupled to Variable Speed Electric Motor.

for economical working on the careful grouping of tools so that the minimum amount of idle shafting is kept at work. Theoretically, of course, the question resolves itself into an equation in which the cost of power, the price at which the motors and the necessary regulating gear can be bought, and the cost of maintenance, coupled with the interest and depreciation allowance which the manufacturer considers necessary on his capital outlay, are principal factors. Practically, it is often a question of what capital sum the manufacturer has available at the time of changing over. The aim of the engineer responsible for the new arrangements should always be to get the most economical result from the capital which it is permissible to spend.

The engineers' requirements as to tools resolve themselves into two classes, those in which the tool is fixed and the work is brought to the tool, which have been referred to above, and the increasing number of cases in which it is more convenient and economical to bring the tool to the work. Electrically-driven portable tools have recently been much improved, and may be divided into two classes. In one class the motor is an integral part of the tool, in the other the motor is separate, and the power is transmitted to the tool by a flexible shaft, or in some cases by ropes.

Portable tools are chiefly used for drilling purposes, but they are also made for tapping, reaming, milling, and similar work, where it is difficult, if not altogether impossible, to do the work by means of a larger stationary machine. The reaming out of holes in ship or girder work where the holes do not line out quite correctly for riveting, is a typical instance of a case where the use of a portable tool saves a great deal of labour. Milling key seats in shafting, boring holes in large castings, and grinding irregular surfaces to a finish are other operations, which to an increasing extent, are being done by electric portable tools. The tapping of locomotive stay bolts is another operation which is more easily and economically carried out in this way than with

the special appliances which hitherto have been considered necessary.

In its application to portable tools electric power has to meet a serious competitor, namely, compressed air, which, by reason of the longer time it has been in use, has many advocates. It may at once be admitted that compressed air has many advantages; it is easy of application, the tools are fairly strong, and it enables great saving in the labour bill to be effected. In the early forms of electric portable tools a good deal of trouble was experienced, due to the armatures burning out if the tool stopped, but the improvements which have been made in later designs have made these stoppages almost a thing of the past, and established the reputation of the tool as a reliable as well as an efficient piece of machinery.

It should be noted that the transmission and utilisation of power by compressed air is inherently uneconomical, and it is only the great saving in labour possible by its use, which has to a large extent obscured the wasteful nature of the transmission system, and permitted pneumatic plant to be tolerated.

The comparative efficiency of the two systems of working, namely, compressed air and electricity, is illustrated by the following figures obtained in a shipyard on the Tyne:—

Size of Hole.	Pneumatic Tool.	Electric Tool.
Drilling holes $\frac{7}{8}$ in. diameter.	Required $22\frac{1}{2}$ cub. ft. of compressed air per minute $= 4\frac{1}{2}$ H.P.	Required 3 amperes at 220 volts = 660 watts, say 1 H.P.
Drilling holes $1\frac{1}{4}$ in. diameter.	Required 38 cub. ft. of compressed air per minute $= 7\frac{1}{2}$ H.P.	Required 4 amperes at 220 volts = 880 watts, say $1\frac{1}{3}$ H.P.

One of the principal difficulties with a compressed air installation is to keep it free from leaks. These leaks are difficult to find, and may prove very wasteful and expensive. Thus, to compress 5 cub. ft. of air to 100 lbs. pressure may cost anything between one penny and twopence, and this amount may easily leak in an hour through a hole barely $\frac{1}{16}$ in. in diameter. The slight noise of the escaping air is masked by the other noises in the shops, yet if undetected, each such leak may mean about five shillings per week loss.

The relative advantages as regards drilling may be seen by the following examples which are based on actual costs:—

(*a.*) *Drilling* 100 *Holes* 1¾ *in. diameter through Steel Plates* 3 *in. thick in stem of Ship, at Dockyard.*

	By Hand.	Compressed Air.	Electricity.
Cost of power -	...	£0 3 2	£0 0 10
Cost of labour -	£3 2 6	0 18 4	0 17 0
Total cost	£3 2 6	£1 1 6	£0 17 10

(*b.*) *Drilling* 500 *Holes* 2 *in. diameter in Mild Steel Plates* 2 *in. thick.*

	By Hand.	Compressed Air.	Electricity.
Cost of power -	...	£0 17 0	£0 3 10
Cost of labour -	£35 8 4	11 3 0	10 12 0
Total cost	£35 8 4	£12 0 0	£10 15 10

These figures do not include the proportional maintenance and interest and depreciation charges which should be

added to the compressed air and electricity figures; but they show in the first place, the great saving in labour cost which may be effected by the use of portable tools of whatever type over hand labour, and secondly, that both as regards the cost of power and of labour the electric tool has the advantage. In all these cases the cost of power for both systems is taken on the same basis, the compressed air system has been considered air-tight, and the labour has been taken at piecework rates for hand labour and time rates for the other cases.

Fig. 67.—Electric Drill combined with Magnetic Drill Post.

Another advantage which electric drills possess is the possibility of combining them with a magnetic drill post as shown in Fig. 67. This consists of an electro-magnet placed in the base of the supporting pillar which is energised by current from the works circuit. This, by its adhesion to the surface of the iron or steel plate to be drilled, saves a great deal of time and trouble in adjusting the tool.

For drills and other tools where the power required does not exceed 2 B.H.P. the flexible shaft forms a convenient and valuable means of connecting the tool cutter to the motor shaft. It enables a separate motor to be used, and allows the tube to be bent through any angle so that work can easily be done in places otherwise very difficult of access.

These shafts consist of a core containing several spirals of wire wound in layers running in opposite directions, which core revolves in a casing of square section steel wire, which serves as a bearing throughout its entire length. Phosphor bronze bearings and metal sleeves are provided at each end, and a universal coupling is usually used to connect the flexible shaft to the motor axle.

A combination of such a shaft with a motor placed on a trolley which can easily be wheeled from place to place, and

Fig. 68.—Electric Drill for Direct Currents, with Two Speeds.

a drill fitted with a magnetic drill post, forms a tool the value of which can only be proved by experience.

Both Messrs Kramos Ltd. and the Consolidated Pneumatic Tool Co. Ltd. have specialised in the manufacture of these portable tools, and have produced designs which can thoroughly be depended on in actual work. For hand work the breast drills are made as light as possible, the former Company making one which will drill a $\frac{3}{16}$-in. hole through a steel plate $\frac{1}{4}$ in. thick or a brass plate $\frac{5}{16}$ in. thick when running at about 900 revolutions per minute, and taking about $1\frac{3}{4}$ amperes at 110 volts, or

about $\frac{1}{4}$ H.P., while weighing complete only 14 lbs. The latter Company's smallest pattern weighs 13 lbs., the drill runs at 700 revolutions per minute, and takes up to a $\frac{3}{8}$-in. bit. It is capable of drilling steel $\frac{3}{8}$ in. thick, requiring at full load about $\frac{1}{2}$ H.P.

In Fig. 68 we have a slightly heavier form of the Consolidated Pneumatic Tool Co.'s pattern. It has under the motor a gear box which gives two drill speeds, namely, 600 and 400 revolutions, and weighs 19 lbs. The overall

Fig. 69.—Electric Hand Grinding Machine.

length is only $15\frac{3}{4}$ in., and it can be wound for either 110 or 220 volts direct current.

When the hole to be drilled is larger than $\frac{3}{8}$ in. diameter in iron or steel, it is necessary to have some form of drill post against which the feed screw of the tool may press. These are supplied in various forms, one of the most popular forms with the electric drill being the magnetic drill post already referred to.

Till quite recently these portable tools were only suitable for use on direct current circuits, but they may now be obtained fitted with alternate current motors having the necessary starting torque. In the larger patterns of drills two

armatures are sometimes used, revolving in a field having one common field and gearing through a planetary gear system to the tool. This method of construction is stated to allow the weight of the tool to be kept low, and one of these tools made by the Consolidated Pneumatic Tool Co., weighing complete only 52 lbs., is capable of drilling a 2-in. hole through steel plates approximately 2 in. thick, taking about 2½ H.P.

Drills, however, are only one form of these tools, air blowers form a very convenient portable tool, and the hand grinder, shown in Fig. 69, is rapidly proving itself invaluable

Fig. 70.—Electric Portable Grinding Tool for Internal Work.

for finishing off castings, while Fig. 70 shows a grinder for use in internal work in cylinders and other places.

These are only a few examples of what is being done with electric portable tools. They can be used wherever a suitable electric supply is available, the only outlay being the cost of the particular tool. A length of flexible conductor with an adaptor terminal enables connection to be made for the smaller sizes with any convenient lampholder, and their use does away to a large extent with the necessity of moving heavy castings from one part of the shop to another during the process of finishing off.

CHAPTER XIII.

MISCELLANEOUS APPLICATIONS OF ELECTRIC POWER.

How Electric Energy is being used in the Arts—Electric Motors in Flour Mills—Bakehouses—Wood-working Shops and Saw Mills—Laundries—Cement Works—Paint Mills—Electric Hoists and Runways—Electric Travelling Cranes—Combined Travelling and Jib Crane—Calico Printing and Paper-Making Machines.

THE applications of electric power in other industries are so varied and in some cases so unexpected that little can be done except give them a passing reference. In some instances the electric current is used as a motive power, and in others as the active agent in bringing about desirable changes. Amongst the latter may be mentioned the production of ozone by means of the silent discharge of high tension electric currents between metallic plates, dry air being slowly drawn through the apparatus, the ozone being used as a valuable purifying agent. An apparatus of this character is used to impart a white tint to low-grade flours. This process, termed "ageing," is said to improve both the appearance and quality of the flour.

A further application of this high tension discharge is the production of nitrogenous products—for use in the manufacture of artificial manures—from the atmosphere. In view of the possible exhaustion of sources of natural manures, this method of producing them by other means may some day assume great importance.

The action of the electric current in decomposing solutions and mixtures of metallic salts when passed through

them is well known, and the industries which have been created by making use of this property are rapidly becoming of great importance. Amongst these may be mentioned electro-plating, electro-galvanising, the manufacture of electrolytic copper, the manufacture of aluminium, calcium carbide, alkaline salts, and more recently the application of electric furnaces in steel works.

Confining our attention, however, to the older industries it may be noted that the miller has a large amount of machinery which it is possible to drive by means of electric motors. One of the largest flour mills in the country, namely that at Dunston-on-Tyne, belonging to the Co-operative Wholesale Society Ltd., has discarded an up-to-date steam plant, and installed over 1,500 B.H.P. in electric motors. The whole of the machinery, including the many conveyor belts which carry the wheat to the various cleaning and drying rooms, are driven electrically, electric lighting being used as a matter of course. The whole of the energy required is purchased from the County of Durham Electric Supply Co. Ltd., and the financial results are said to amply justify the abandonment of the steam plant.

Electric motors are being extensively used in bakehouses. Here there are a number of small machines, such as mixers, kneaders, weighers, and dividers, which are usually best driven by small separate motors. They are only used intermittently, and it is better to place them just where they are wanted than attempt to economise in the first cost of motors by arranging them in groups and introducing shafting. The cost of working with energy at a reasonable rate, say one penny or three halfpence per unit, compares favourably either with hand labour or with gas engine driving, while the output as well as the reputation of the bakehouse is perceptibly increased.

Great use has been made of electric driving in woodworking shops and saw mills. Messrs A. Ransome & Co. have done much to popularise this method of working. An

interesting application of the adaptability of the electric motor is found in the Ransome & Lavo band saw used for cutting up timber logs. The driving motor is built round the driving pulley of the saw, and so dispenses with all belting and shafting. The motor is slow speed, and has to be capable of developing up to 50 B.H.P., but its use not only reduces the floor space occupied by the machine by practically one-half, but at the same time increases the speed of working, and by the steady nature of the cuts allows a larger number of planks to be cut from a given log.

Circular saws, band saws, tenoning, morticing, and boring machines, are favourable subjects for separate driving, while planers and moulders are often arranged for group driving.

The following figures which appeared in the paper, *Timber and Wood Working Machinery*, show what can be done by adopting electric driving.

Taking eight different works, each driven by a steam engine, the following were the *average* amounts of power required and used:—

Length of shafting	458 ft.
Number of pulleys	138
Length of belting in use	2,446 ft.
I.H.P. with plant loaded	46·2 I.H.P.
I.H.P. running light	16·6 I.H.P.
I.H.P. absorbed in shafting	29·6 I.H.P.
Percentage of I.H.P. absorbed in shafting to I.H.P. developed	56·08 per cent.

These show that in ordinary working there is a wide margin of power which may be saved. That the above are average conditions is shown by the following figures given by the owners of a wood-working factory in the north of London.

Before conversion, the works were driven by a steam

engine, and contained thirteen machines, the cost of driving for a normal quarter being :—

Coal (in addition to wood waste) -	£34	0	0
Water and stores - - - - - -	5	10	0
Repairs - - - - - - - -	7	10	0
Attendance - - - - - - -	20	0	0
Total - -	£67	0	0

The works when changed over to electric working were arranged as follows :—

	Size, Motor. B.H.P.
Two single spindle moulding machines, speed 5,000 revolutions per minute - -	3
One Smith's morticing machine - - - -	3
One emery grinding machine - - - -	2
One tenoning machine, 8 by 6 in. cutter heads, single scribing block - - -	5
One single spindle - - - - - -	2
One 30-in. band saw, One boring machine } driven by countershafting from one motor	5
One combined surfacing thicknessing machine	5
One surfacing machine, One 24-in. thicknessing machine } driven by countershaft from one motor - -	5
One 36-in. circular saw bench - - -	15
One 12-in. rising and falling table grooving and cross-cutting saw bench - -	5
One 30-in. pendulum cross-cut saw - -	5
One 12-in. by 4-in. four cutter planing and moulding machine - - - - -	20

a total of fifteen machines, with motors aggregating 75 B.H.P. The last two machines, requiring motors of 20 B.H.P. and 5 B.H.P. respectively, were added after electric driving was adopted.

Current was purchased from the Hackney Borough Council at a fraction under one penny per unit, and the cost of current for a heavy quarter's work after the last two machines were at work was - - - - - - £25 5 4
while the expenditure on stores and repairs
did not exceed - - - - - - 1 0 0

or a total of - - - - - £26 5 4

showing a saving of practically £40, or per annum of £160.

These figures do not take account of interest and depreciation charges on the capital cost of the conversion, which would amount to about £600, 10 per cent. on which would be £60 per year or £15 per quarter, still leaving a gain of £100 per year as the result of the change.

Laundries, too, have been invaded by the electric motor, and nearly all the newer plants are electrically driven. It is surprising how many machines there are in a modern laundry many of which may easily be arranged in groups, and driven from a few motors, preferably placed outside the workrooms on account of the moist atmosphere. There is, however, a gain in speed of working in many cases if the ironing and pressing machines are driven separately, and speed control to suit the special class of work is arranged for.

Cement works afford many opportunities for electric driving. In modern works its advantages are well recognised, and the electric power house is one of the most important departments of the works. The clay and chalk are roughly ground, and then passed to the mixing ponds where constant agitation is necessary. This is effected by the slow movements of wooden paddles which are geared to electric motors mounted on the frame over the ponds, and afford good examples of the hardiness and reliability of the modern motor.

After thorough mixing, the semi-liquid mass is raised by

electric pumps to a number of troughs passing over the entrance to the rotary kilns. These consist of long large steel cylinders lined with firebrick kept in constant slow rotation by electric motors gearing into a toothed wheel surrounding the cylinders. The kilns are placed in an inclined position, so that the mixed chalk and lime gradually falls from top to bottom. The lower end of the kiln is intensely hot, due to the combustion of a fine stream of coal dust—electrically ground—which is blown into the kiln and rapidly burns up. The mixture in falling is first dried, and then thoroughly calcined, falling at last in a red-hot mass into another rotating cylinder, in passing down which it is cooled. In some works the wagons which carry the "clinker," as the fused mass is termed, to the mill, are propelled and raised to the top of the mill electrically, and in nearly all cases the mills themselves which grind the cement into the exceedingly fine powder in which it is sold are driven by electric motors. The cask making department of the works affords further opportunities for electric driving which are often utilised to their full extent.

Paint mills, where the use of separate motors to the different grinding machines enables the rate of working to be varied to suit the different pigments, sweet manufactories, butter factories, cold storage works, and breweries are only a few of the many other industries where electric motors are being extensively adopted. Electrically driven blowers are superseding all other methods of working in smiths' shops and foundries, electrically driven exhaust fans are being used to keep workrooms free from dust, and to minimise danger to workers where dangerous processes are carried on; in fact the electric motor bids fair to become the most widely used of all forms of obtaining power for small industrial purposes.

One of its most important uses has not, however, been mentioned. This is the transport of material during manu-

facture from one part of the workshop to another. Much has been done in modern workshops by the better arrangement of tool positions and the use of portable tools to reduce the amount of movement of material necessary, but manufacturing costs would be much higher than they are to-day if the electric crane in its various forms were not available.

In the introductory chapter reference was made to the economy which the use of an electric overhead travelling crane made possible, and of the convenience, easy control, and constant working at maximum rate which is associated with its everyday working. The large amount of unskilled labour which can be dispensed with when electric overhead travelling cranes are in use was also mentioned. The same may be said of the jib cranes, capstans, hoists, transporters, and electric locomotives which are being used more and more in works, docks, railway yards, and all large industrial establishments. A book could easily be filled with descriptions of what has been accomplished in this direction, for in this field electric power has proved itself far superior to the older methods it displaced.

In factories the necessity for easy transport of material from one place to another is not of such paramount importance, as the quantities of material handled at one time are usually small and may be carried by hand or wheeled in a trolley. In some directions, however, particularly in engineering workshops, overhead travelling cranes are used, while for other purposes there is a growing demand for electric hoists and runways.

These latter consist of an electric hoist running on the under flange of an I steel girder which is carried along the route to be traversed by the goods. The hoist motor is mounted on a small carriage, receives energy from two conductors fixed above the girder, and is operated in small sizes from the floor; in larger sizes a seat for a man is provided on the hoist from which the various movements are

controlled. Separate motors are usually fitted for the lifting and travelling motions. A runway of this type was recently installed at a large timber store in Leeds by the Morley Electrical Engineering Co. The hoist had a double spiral barrel to give a vertical lift, all the gearing was of cast steel with machine cut teeth, the driving wheels being fitted with ball bearings. The hoist was provided with an automatic mechanical brake actuated by the load in addition to the electro-magnetic brake on the motor operated by the handle of a controller of the type described on page 73 (Chapter III.). Swivelling bogies were in this instance fitted to the carrier to enable the transporter to run round small radius curves.

A 4 H.P. series wound direct current motor gives a hoisting speed of 30 ft. per minute with a full load of 1 ton, or 50 ft. per minute with no load, and a 2 H.P. series wound motor a travelling speed of 250 ft. per minute at full load.

In smaller sizes the travelling motor is sometimes dispensed with, the hoisting being done electrically, but the load being pulled along from the floor. These runways are in some respects a development of the telpherage system of transport developed by Professor Fleeming Jenkin nearly twenty years ago in which an electric travelling carriage ran along a suspended wire rope.

Electric travelling cranes are now common in all sizes from 1 ton upwards. They are rapidly superseding both the old steam crane, where a portable engine and boiler complete was mounted on the crane, and the flying rope and square shaft cranes, all of which were very inefficient. In these cranes there was a continuous loss of from 6 to 8 H.P. per 100 ft. of shop length due to friction losses, and the crane could not be worked at light load any faster than the full load speed for which it was designed.

In the electric crane, especially when separate motors are employed for the lifting, traversing and travelling movements,

any desired variation of speed can be obtained, and for lifting, two sets of gearing, one designed for heavy loads with comparatively slow movement and the other for light loads and correspondingly rapid movements, can be employed.

As crane motors only work at full power for short periods at a time, they may be rated on a more liberal basis than motors needed for continuous working. This was referred to in Chapter IV., page 91. They are usually direct current series wound and used in connection with drum type controllers of the general type described in Chapter III., pages 69 to 76. These are fitted with an electro-magnetic brake, but some makers prefer to supply in addition an electro-magnetic friction brake. In many cases where only alternating currents are available, induction type motors fitted with slip rings have been used with marked success. In these cases variable speeds are obtained by introducing resistances into the rotor circuits of the motors.

It is, however, very probable that the single-phase commutator type motor will come into extensive use for crane work; its high starting torque and easy speed control render it very suitable for this class of work.

The tendency at the present time in crane design is to employ higher speeds of working, especially for the traversing and travelling movements, than in the past. This means slightly larger motors and increased first cost, but the gain in valuable time in everyday working is very great.

The following table is interesting as showing what are the standard speeds for the various motions of three motor overhead cranes recommended by Messrs Vaughan & Son Ltd., who are well known as specialists in overhead crane construction :—

Normal Capacity of Crane.	Standard Speeds.		Longitudinal Travelling without Load.
	Hoisting.	Cross Travelling without Load.	
1 ton.	50 ft. per min., full load.	100 ft. per min.	300 ft. per min.
2 tons.	35 ,, ,,	100 ,,	300 ,,
3 ,,	30 ,, ,,	100 ,,	300 ,,
4 ,,	25 ,, ,,	100 ,,	300 ,,
5 ,,	5 tons at 20 ft. per min.	100 ,,	300 ,,
10 ,,	10 ,, $12\frac{1}{2}$,, 5 ,, 25 ,,	100 ,,	300 ,,
15 ,,	15 ,, 8 ,, $7\frac{1}{2}$,, 16 ,,	80 ,,	300 ,,
20 ,,	20 ,, 8 ,, 10 ,, 16 ,,	80 ,,	300 ,,
25 ,,	25 ,, 6 ,, $12\frac{1}{2}$,, 12 ,,	80 ,,	250 ,,
30 ,,	30 ,, 6 ,, 15 ,, 12 ,, 5 ,, 25 ,,	80 ,,	250 ,,
40 ,,	40 ,, 6 ,, 20 ,, 12 ,, 5 ,, 33 ,,	80 ,,	250 ,,
50 ,,	50 ,, 6 ,, 25 ,, 12 ,, 5 ,, 33 ,,	80 ,,	250 ,,

A recent design of revolving jib crane in which a revolving jib is suspended underneath an overhead traveller has many advantages where it is desired to be able to lift weights in any part of a shop. One recently made by Messrs Applebys Ltd. had a capacity of 2 tons, and was suspended under an electric traveller with a 25-ft. span. The control cage was fitted on a balancing extension of the jib arm. There were four motors, one of 3 B.H.P. for lifting, one 3 B.H.P. for slewing, one $1\frac{1}{2}$ B.H.P. for travelling, and one $1\frac{1}{2}$ B.H.P. for traversing. This crane enabled goods to be lifted not merely from any point directly underneath the centre bay, but from any part of the side bays covered by the arm of the jib portion of the crane.

In calico printing and paper-making factories the question of adopting electric power does not depend entirely on comparisons of cost. In industries of which these are typical, it is necessary to use large quantities of steam either in the various processes or to humidify the atmosphere. This steam must be generated, and the question to be faced is, whether it is better to generate it at low pressure, or to produce it at high or medium pressure, use it in steam engines, and employ the exhaust steam in the factory for the various purposes required. There is a feeling amongst many mill-owners that under such conditions it is immaterial what is the efficiency of the steam engines—the more steam they use, the more exhaust steam is available in the factory. Hence there has been a tendency to use separate steam engines for special machines, and to treat as inevitable the heavy losses from radiation and heat leakage which followed as a natural result from the long lengths of partially unprotected steam and exhaust pipes.

In cases like this, the electrical engineer should remember that steam-raising plant must be provided in any case, and the necessary attendance provided, and that if electric energy is to prove itself to be the best form of power, it must suit the working conditions better than the steam drive, and so enable larger outputs of better quality to be obtained. There will be a distinct saving in the cost of fuel if the steam required for manufacturing operations is only generated at low pressure instead of all being raised to the engine pressure, and part of it being then reduced by a reducing valve.

Even under these conditions the use of electric power has made rapid and substantial headway. A considerable number of the best firms have adopted electric driving to a greater or less extent, and have found the result satisfactory. If there is no public supply of electric energy available, and the current is generated on the premises, there will be a certain proportion of exhaust steam available for factory use,

but owing to the more efficient engine and conditions of working, this will be considerably less than before. It will often be found best, if the amount of low pressure steam required is considerable, to divide the steam-raising plant, and only raise to the engine pressure the amount needed for the engine. The saving which can be effected in this way depends, of course, upon the location of the factory and the cost per ton of coal.

In calico bleaching and printing works it is in many cases best to arrange for separate driving, and if possible to obtain a supply of direct current, as this enables speed regulation within wide limits to be easily carried out.

A preliminary process is to pass the material quickly quite close to a gas flame, after which it goes to a washing machine. Each of these motors may be shunt wound machines, preferably controlled from a point near the singeing machine, so that the speeds of the two machines can be suited for the same length of material.

To bleach the material it is next passed through a series of machines termed the liming, chemicking, and souring machines, and then through several washing and squeezing machines. Each of these machines is usually fitted with separate motors, with several definite running speeds, and fine adjustment near these standards to suit special requirements and facilitate one machine taking the material untouched from the previous process. The various drying machines afford another opportunity for the use of directly coupled motors, and in many works the fan used for exhausting the steam from the drying room is electrically driven.

In the dyeing rooms there are a further number of machines, some of which need separate motors and long range control, while others are best driven in groups from a larger motor. In all these cases the motor should be of the entirely enclosed type, and placed as far out of the steamy atmosphere as possible.

In the printing house proper there are the stentering, calendering, printing, and drying machines to be considered, and for most of these separate control is desirable.

In the calico printing machines it is necessary to arrange for very slow movements or "inching" in a similar manner for ordinary paper printing work, and the same methods of control, described on pages 241 to 246, Chapter XI., are made use of.

It will therefore be seen that for this class of work the electric drive has many advantages, and no surprise will be felt that many of the bleaching and calico printing works in Lancashire have either adopted or are considering this system of working.

The main machines used in paper mills are usually of large size, and if converted to electric driving, nearly all are suitable for separate motors with their consequent independent control. The first process consists in "beating" or tearing the material used, whether wood, manilla, jute, or flax rags, to a pulp. These machines vary greatly in size; they are usually direct coupled to motors and arranged for working at variable speeds. Considerable overload capacity must be allowed in the motors.

Plenty of water is a necessity of paper mills, and for driving the centrifugals usually employed for circulating this water, direct coupled motors are very useful.

The paper-making machines proper often require motors of 80 B.H.P. to 150 B.H.P., or even larger, and need speed control over very wide ranges.

An ingenious method of securing this has been used by Messrs Siemens in one of their installations. The current for driving the mill is obtained from a turbo-dynamo consisting of two dynamos coupled in tandem, and directly connected to a steam turbine. Each dynamo gives about 500 K.W. at 230 volts. It is therefore possible to use a three-wire system with 460 volts between the outers.

The motors for the paper-making machines have two

armature windings and two commutators. The motors are fitted with "interpoles" to reduce sparking, as described on page 35, Chapter I., and have three normal speeds.

The lowest is obtained by connecting the two armatures in series across the 230 volts between the middle wire and one of the outers; the intermediate standard speed by connecting the two armatures in series between the outer or 460 volts; and the highest standard speed by connecting the two armatures in parallel across the 460 volt outers. The motors will give 80 B.H.P. at the highest speed, and by means of shunt regulation may be controlled from about 75 to 600 revolutions per minute, or through a range of 8 to 1.

In other cases this control is obtained by using a separate dynamo for each of these special motors and controlling the motor speed by varying the resistance in the shunt circuit of the dynamo.

There are also a number of drying and calendering machines, as well as paper-cutters and other small but important accessories. These may either be grouped or driven separately, the choice of the best method depending upon the particular conditions.

For all this class of work the flexibility of the electric drive and the easy control of the speed of motors throughout a wide range are advantages which enable it not only to compete in cost, but to give largely increased outputs of finished work.

CHAPTER XIV.

THE INSTALLATION OF ELECTRIC MOTORS.

Need for Care in using Electric Power—Home Office Regulations—Institution of Electrical Engineers' Rules—How to run Cables—Manufacturer's Responsibilities with Purchased Energy—Notes on Works Generating Plants—Switchboard Arrangements—No Volt Release Switches—The Need for Qualified Attendants.

THERE is no system of power distribution which does not require care to be taken in using it in order to prevent accidents. Electric power is no exception to this general rule, though if carefully installed and properly maintained, the risks of accident are very small.

These risks are largely due to the fact that the senses of seeing and hearing are not affected by a leakage of electric current, and that an electric shock at a given pressure has different effects not only on different persons, but on the same person at various times. The electrical resistance of the human body varies with its condition within very wide limits, and an electrical pressure which may be harmless at one time may be fatal at another. The presence of perspiration on the skin rapidly reduces the electrical resistance of the body, and care should be taken when in that condition to avoid electrical shocks.

The points to be aimed at, in installing electrical plant, are, first, the prevention of any leakage of electricity either when the motors are idle or at work, and second, the provision of good earth connections so that, should any leakage occur, no point accessible to workpeople may become charged with electrical pressure.

The Factory and Workshop Act of 1901 empowered the Home Office to issue regulations controlling the conditions under which electric power might be used in factories and workshops, whenever it deemed such a course advisable.

A draft set of Rules was issued in August 1907, and as a number of objections were raised to them; an inquiry was held in the early part of 1908 at which these objections were fully discussed. As a result, the Rules have been modified, and in the future they will form the minimum standard of precautions which must be observed when installing electric power.

There is much to be said for thus ensuring a standard of workmanship which will render electric power one of the safest of known power distributors. The conditions are in no case impossible, and only rarely unreasonable, and the majority of well-designed works installations already conform to them.

As a public inquiry with its inevitable delay must precede any alteration in the wording of the Rules as now issued, it is probable they will influence standard practice for a long period, and so may be looked upon as permanent.

They affect all installations using a higher electrical pressure than 130 volts direct current or 65 volts alternating current.

The terms—

Low pressure, as used in the Rules, mean circuits of not more than 250 volts pressure.

Medium pressure, currents between 250 and 650 volts pressure.

High pressure, voltages between 650 and 3,000 volts, and

Extra high pressure, circuits of more than 3,000 volts pressure.

At the same time, it should be remembered that the Home Office Rules are only concerned with the safety of the worker; and while this is all-important, there are other considerations to be observed, if the best results are to be

obtained. The technical requirements of an electrical installation are well provided for, in the Rules which have been prepared and issued by the Institution of Electrical Engineers. These Rules have been accepted by the greater number of the fire insurance companies, and it is advisable that whenever an order is placed for installing electric plant, it should be distinctly stated that the work must be carried out in accordance both with the Home Office Regulations and the Institution of Electrical Engineers' Rules.

If this is done, it is needless to point out the importance of using well-insulated copper cables, since this is insisted on as a primary necessity. The sizes to be used to carry different currents are also given, and the permissible pressure drop in long runs of cable defined. It is specified that the cables must be run either in steel conduits, well-seasoned wood casing, or on insulators fixed to the walls and ceilings in suitable situations. The cases in which bare copper wires may be used inside buildings are also stated. For interior work, rubber covered cables are generally employed, though paper insulated lead covered cables have much to recommend them. If used they must, however, be effectively sealed from dampness at each end. The rubber cables should be insulated with layers of pure and vulcanised rubber thoroughly compounded and protected with a covering of tape and braid. The insulation resistance taken after twenty-four hours' immersion in water and one minute's electrification should not be less than 600 megohms per mile, and they should, if used for 200 volt circuits, be certified as having withstood a pressure test of less than 1,000 volts applied for thirty minutes.

Where possible, steel conduit is the best protection for the cables. This is made in three qualities—open-seam tube, which is suitable for dry positions, brazed tube, which is best for ordinary work, and screwed tube, which should always be used in damp places. The importance of pre-

venting moisture condensing in the insides of conduits cannot be over-rated.

It pays to provide good quality cables and run them in suitable steel conduits, in the freedom from break-downs and anxiety which results.

Where energy is purchased from an outside source, the supply authorities lay the service cables, and supply energy at the declared pressure through a meter and double pole fuse which they provide and fix on the premises, and then seal to prevent any one tampering with them. The consumer must provide the double pole switch, which enables him to switch off the current from the entire installation when necessary.

In the case of large consumers, where the power required amounts to several hundred horse-power, the supply authorities generally provide a substation on the consumer's premises where the energy is transformed from the high pressure of transmission to the declared pressure of supply. Some hundreds of these works' substations exist in the Tyne and other manufacturing districts, and descriptions of the switchgear arrangements are very interesting. These substations are, however, under the control of the supply authorities, and they do not directly concern the manufacturer.

If the energy is generated on the premises, the manufacturer is, of course, responsible for the whole plant. As much free space as possible should be allowed round the generating units, and the cables from the dynamos to the switchboard should be carried underground in steel tubes. Neglect of this precaution has been in the past a frequent cause of break-down, and nothing looks more untidy and unbusiness-like than to see a number of cables lying about an engine-room floor saturated with oil and causing trouble to every one concerned.

It is not possible here, to enter into the question of the design and arrangement of works generating plant. It is

sufficient to say that a small expenditure on glazed bricks, good floor tiles, paint, and whitewash is a good investment. Get the generating plant and its surroundings as clean and tidy as possible in the first place, and insist on its being kept in the same condition, and you have gone a long way towards keeping your costs of working a minimum.

It pays, too, to keep the plant in good condition; any defect should be at once reported and put right.

It is also good practice to see that a meter to register the whole output of the dynamos is fitted on the switchboard. Strict account should be kept of all purchases, and the cost of all labour should be recorded; and simple forms giving these details and the cost per unit generated should be prepared and given to the works manager each week. A report on the causes of all break-downs and accidents should also be insisted on. In this way a close check can be kept on the working of the plant, and any fault can be at once located and remedied.

The switchboard should be as simple as possible in its arrangements, but fitted with thoroughly reliable apparatus. A clear passage-way, not less than 3 ft. wide, should be left at the back with adequate means of access, and the board must be fenced off, and no one but authorised persons should be allowed to operate it.

Care must be taken that all switches are quick break, and cannot be left in partial contact, and that all fuses are so guarded that there is no danger from overheating or from the scattering of hot metal when they come into operation.

The board itself should be either of enamelled slate or marble, mounted on angle-iron framework. The old practice of surrounding the board with a massive ornamental wooden frame has fortunately fallen into disuse; it was a waste of money and a source of danger.

At the switchboard, provision should be made for the measurement and control of the circuits from the generators, and also for the distribution of the energy either to the

various motors, or to distributing centres in other parts of the premises. In the majority of cases double pole switches should be fitted not only to every generator circuit, but to all the distribution circuits. Fuses are also necessary for the protection of the circuits from overload. In many cases it is possible to combine the switches and fuses by using switch fuses, where the fuse wire either passes through a porcelain handle with well-protected ends, or under the handle thoroughly shielded from risk of contact with the operator. Such fuses permit of easy and safe replacement.

Each motor must be fitted with a double pole switch and fuse, or switch fuse in addition to the starting switch. These are usually enclosed in cast-iron boxes, and illustrations of several patterns are given in Chapter III. There was a great deal of discussion on the proposal made by the Home Office that automatic circuit breakers of the no volt release pattern should be fitted to all motors of larger output than $\frac{1}{3}$ H.P. It was pointed out at the inquiry that in the experience of many engineers this was quite unnecessary. Such accessories can easily be fitted as part of the starters for direct current motors, but it is not so easy to arrange them to work in connection with induction type alternate current motors. Several patterns of this automatic circuit breaker for alternating currents are now obtainable at a moderate cost. It was shown that fully 95 per cent. of the alternate current motors at work in this country had no such protection, and that its strict enforcement might prove detrimental to the industry. The Home Office at length agreed to modify their requirement, and they now ask that every motor or group of motors which is not under the supervision of an attendant constantly at the controller, shall be protected by an automatic release which, in the event of a motor stopping, shall at once replace all starting resistances in circuit, and render it necessary to operate the starting switches. This is necessary to avoid danger to an attendant on a machine through the motor unexpectedly starting, if a

fuse were replaced in a distant part of the circuit without the knowledge of the person on the machine.

It is also required, that if a motor drives machinery in more than one room, that means for immediately stopping it shall be provided in each room. This is best done in the case of a direct current motor by running a pair of leads from the terminals of the no voltage release coil on the starter to the different rooms where they are connected to bell pushes, which, when pressed, closes the circuit and short circuits the no voltage coil. The motor is thus at once stopped, the starter switch arm returning to its off position.

The Home Office insist that only authorised persons, or those acting under their immediate supervision, shall undertake work where technical knowledge or experience is necessary. This is a wise provision, and the choosing, and, if necessary, training, of an employee to look after, and be responsible for, the maintenance of the plant henceforth becomes a legal duty as well as a wise precaution. It is perhaps superfluous to point out that as such "authorised persons" have certain responsibilities, they should be remunerated accordingly. The personal element is a very vital factor in keeping the repairs bill of an installation down to the minimum point, and a satisfied attendant—proud of his plant and particular as to its working—is a distinct asset to a business undertaking.

It must be borne in mind that with electrical as with other forms of power distribution, common-sense must be exercised if accidents are to be avoided. The annual reports both of the electrical inspector of factories and workshops to the Home Office, and of the engineers of the various insurance companies undertaking the maintenance of electrical machinery, show how many of the accidents which take place are due to entirely preventible causes; in many cases, it seems as if it were the result of an entire absence of ordinary care.

CHAPTER XV.

THE LIGHTING OF INDUSTRIAL ESTABLISHMENTS.

The Importance of Good Lighting in Offices and Workshops—What is Light?—Types of Electric Lamps—Carbon Filament Lamps—Metallic Filament Lamps—Nernst Lamps—Open Type Arc Lamps—"Enclosed" Arc Lamps—"Flame" Arc Lamps—The "Magnetite" Arc Lamp—Mercury Vapour Lamps—The "Moore" Vacuum Tube Lamp—Requirements of Commercial Offices—Drawing Offices—Textile Factories—Engineering Workshops—General Rules.

THE proper artificial illumination of industrial premises has a great deal to do with the profit-earning capacity of the undertaking. The length of time during which artificial illumination is required depends upon local conditions, such as the length and division of the working day, the character of the surroundings, and the prevalence of overtime, but it rarely averages out at less than 10 per cent. of the total working hours, while it often exceeds this proportion.

The provision of ample lighting during the daytime is receiving more attention than in the past. It has been found that the cost of keeping an odd man to clean windows repays itself in the general improvement in the appearance and output of the shops, while the legal insistence upon periodical whitewashing has not only brightened up the shops but encouraged better ventilation and improved sanitary conditions all round. The unhealthy close dens which used to serve as workshops are rapidly disappearing, and the modern factory leaves little to be desired from the

point of view of brightness, and in many cases of good ventilation.

Attention to these points may appear superfluous, but really, they are the very essence of financial prosperity. The evidence of those up-to-date manufacturers who have distinguished themselves by their attention to the conditions under which their work is carried on, goes to prove that the forethought and money thus expended has had a great deal to do with their personal success.

It may therefore be said that it pays to consider carefully the method and arrangement of the artificial lights used during the hours of semi-darkness. The degree of illumination to be aimed at, is that which just keeps the workers in their state of maximum efficiency. This means a reproduction as far as possible of the conditions of diffused daylight, the avoidance of areas of intense brightness and of as clearly defined shadows, and the provision of sufficient illumination to permit of the operators working without unduly trying their eyes.

The problem as thus stated is no easy one, and in many cases considerations of expense prevent its being solved in its entirety. Much, however, may be done by a study of the particular conditions to be met, and attempts to provide sufficient but not too lavish illumination often meet with unexpected success. In the United States the science of successful illumination is rapidly becoming a profession, and the illuminating engineer is often called in to give expert advice in difficult cases.

It often happens that the question is one of proper distribution rather than an extra amount of light. A number of powerful lamps may be used, but the general effect may still be unsatisfactory; there are parts of the floor painfully brilliant, and parts so imperfectly lit that careful work is impossible. The efforts of the works manager and the engineering staff should be directed towards obtaining even intensity of illumination over the whole of the floor area.

The best means to be adopted to secure this, differ in almost every case. So much depends upon the size of the shop, its general character, its height, whether it has a roof or a flat ceiling, whether there is much overhead shafting or an overhead travelling crane, and above all, on the class of work to be carried on. This latter point is all important, as it fixes the minimum standard admissible, for it will be at once appreciated that a light which is sufficient for a foundry may be quite unsuitable for an operator in a textile factory weaving delicate coloured silk fabrics.

Light, it is well known, consists of waves or vibrations of an imperceptible medium pervading all space, which is generally termed the ether. These waves travel at the rate of 185,000 miles per second, but differ greatly in wave length and consequently in the number passing in a given time. The retina of the eye is affected by ether waves having wave lengths within certain limits, namely from thirty-three millionths of an inch long, which give the impression of red light, to fourteen millionths of an inch long, which give the impression of violet light. The intermediate colours —orange, yellow, green, blue, and indigo—have definite intermediate wave lengths, and waves with a shorter length than the violet, though incapable of affecting the eye, have the valuable actinic or chemical properties which are so useful to the photographer. The mixture of all the above rays gives diffused daylight, their total absence is darkness. It is probable that the eyes of some animals have different ranges of susceptibility to ether waves than our own, and that this accounts for their peculiarities of vision. Other waves have been detected by their effects in different directions, and recent discoveries in science have been largely concerned with investigations into the existence of ether waves which are outside the range of those capable either of affecting the eye or of causing chemical change.

Artificial lights are nearly always deficient in some of these rays, and to that extent are inferior in their effects to

daylight. The usual commercial sources of artificial light produced electrically are:—

A. **The Carbon Glow Lamp.**—The light is produced by the incandescence of a thin carbon thread enclosed in a glass bulb entirely exhausted of air. The lamp has for twenty years held a foremost place in electrical illumination, and many millions of them are in daily use. The light is richer in red than violet rays, and it is therefore imperfect as a colour matcher. Lamps can be used indiscriminately on direct or alternating current circuits, and are made for all pressures up to 250 volts. Their efficiency when new is about 4 watts per candle-power. The candle-power of the lamp deteriorates during use owing to the gradual blackening of the bulb, and there is a point in the life of every long-lived lamp where it is cheaper to discard it and buy a new one than to pay for the extra electrical energy required per effective candle-power.

It is possible to increase the efficiency of the lamp by raising the temperature at which the filament gives out its normal candle-power. This, however, reduces the life of the lamp, as the filament more rapidly disintegrates owing to the higher temperature, and also causes it to blacken more rapidly, and so decreases its effective illuminating power. The result is that the lamp has a shorter effective life, and experience proves that about 4 watts per candle is the most economical efficiency for this type of lamp. Many attempts have been made to popularise 3 and 3¼ watts per candle-power lamps, but they have all been comparative failures, largely owing to the reluctance of the consumer to discard lamps which still burn, though requiring a large amount of power per effective candle-power. It is not at all an unusual experience to find on testing an ordinary installation that the lamps are averaging much nearer 6 watts per candle-power than the normal 4. The carbon filament lamp is also very sensitive to voltage variations, and when overrun—even for short periods—blackening of the bulb is almost

sure to occur. Some years ago attempts were made with some success to popularise the use of high candle power lamps, and 100 candle-power and 200 candle-power lamps in large globes were employed for shops and small factories. The lamps proved in actual use so expensive in first cost, wasteful in energy, and unsatisfactory so far as regards useful life and illuminating power, that they are now practically obsolete.

B. **The Metallic Filament Lamp.**—These lamps have only recently been reintroduced in a commercial form, though the earliest incandescent lamps were all "metallic filament" lamps, being made of platinum wire which was discarded in favour of carbon on account of its low melting point. The discovery of means of isolating the rare metals tantalum, osmium, and tungsten have encouraged chemists to use them in making commercial metallic filament lamps, and at the present time there are a number of very efficient types on the market. Amongst the best known are the "Tantalum" and the "Osram" lamps.

The "Tantalum" lamp is made of a drawn tantalum wire enclosed in an exhausted glass bulb. It was one of the earliest "wire" lamps, and is largely used on direct current circuits. The candle-power may be as low as 16 candle-power on a 100 volt circuit, though 22 candle-power is the usual standard. A great convenience of this pattern of lamp is the small size of the bulb, though large bulb lamps are made, and can be supplied when preferred. The lamp is now sold for use on circuits up to 160 volts, and 200 volt lamps have been made, and will soon, no doubt, be commercially available. The efficiency is from 1·8 to 2 watts per candle-power, and the price from 2s. to 2s. 6d. per lamp. The lamps are said to have an average useful life on direct current circuits of from eight hundred to one thousand hours, though under ordinary conditions the lamps will last on an average for considerably longer periods. Alternating currents, especially at low periodicities, have a curious action

on the tantalum filaments which causes them to rapidly deteriorate while the efficiency is at the same time lowered.

A great deal of attention has been given to this question by the makers, and by improvements in the method of manufacturing the filament and special arrangements for anchoring it, they are now able to obtain a life of about eight hundred hours. The efficiency is, however, slightly lower than when the lamps are used on direct current circuits. The "tantalum" filament is stronger than other types of "wire" filament lamps, and this lamp has been used successfully not only for street lighting, but for omnibus, tramcar, and underground train lighting, where there is a good deal of vibration to be overcome.

The Tungsten lamp is rapidly becoming *the* metallic filament lamp. It is made by a number of firms, and is sold under a variety of fancy names. There are several methods of making the filament, which result in the end in producing a fine thread of nearly pure tungsten. The filament is at best very fragile, exceedingly fine, and is enclosed in an exhausted glass bulb. It can be heated to a sufficiently high temperature to ensure an efficiency of about 1¼ watts per British candle-power. Till quite recently 130 volts was the highest voltage for which they were made, but now a number of 200 to 260 volt lamps are obtainable in sizes down to 50 candle-power. These lamps burn with equal efficiency on direct and alternating current circuits. The "Osram" lamp, sold by the General Electric Co.; the "Metfil," made by the Edison & Swan Co.; the "Sunbeam," by the Sunbeam Co.; the "B.T.H. Tungsten," by the British Thomson-Houston Co.; the "Premier," by the Premier Electric Lamp Co., are only a few of the names by which tungsten lamps are designated. Other names are the "Metalik," the "Meta," the "Aegma," the "Gral," "Adnil," "Sirius-Efesca," "J. S.," "Solium," and "Westinghouse." All have some small improvement in detail to urge, and competition is rapidly reducing the prices of the lamps to

reasonable commercial figures. The life of all these lamps is about one thousand hours, though individual lamps may burn for much longer periods. Till recently they were only suitable for use in vertical positions, but improved methods of anchoring the filaments permit of their burning in any position.

Metallic filament lamps are less sensitive to voltage variations than carbon lamps, and as the filaments are maintained at a higher temperature, the light contains a larger proportion of violet rays and to that extent is more like daylight. The introduction of these lamps with their high efficiency has made a great difference to the prospects of electric lighting, as they permit a better illumination to be given at a greatly reduced cost.

Low voltage tungsten lamps are cheaper in first cost and stronger than the higher voltage type. It is also possible to safely run them at a slightly higher efficiency than the $1\frac{1}{4}$ watts per candle-power usual with 100 volt lamps. They can also be obtained as 25 volt lamps in the 10 candle-power size, as 50 volts as low as 16 candle-power, while in the 100 volt size 25 candle-power is the lowest candle-power, and the 200 volt lamp has not yet been commercially made below 50 candle-power. Where alternating currents are available, it is in many cases economical to use small transformers to reduce the voltage from the pressure of supply to 25 or 50 volts, and use this low pressure current in conjunction with the efficient and comparatively cheap "Tungsten" lamps. In this way considerable savings may be made in energy, the monetary gain depending, of course, on the price charged per unit for electrical energy. If this can be got at prices lower than 2d. per unit, it does not pay to go to any large extra outlay for "economical" lamps, which are used for only short periods, but when 3d. and over is paid for electrical energy, the provision of reducing transformers and the use of "wire" lamps is advisable. If possible, means should be provided for switching the current off the reducing

transformer when the lights are not in use, else the no load losses of the transformer which are constantly going on will neutralise a considerable part of the saving in energy effected by the use of the "wire" lamps.

C. **The "Nernst" Lamp.**—This lamp is specially suitable for use on 180 to 250 volt direct or alternating current circuits. It was the electrical reply to the introduction of the Welsbach gas mantle, and though it is now being largely superseded by the metallic filament or "wire" lamp, it has several features which are of interest. The light is obtained from a short incandescent rod made of a mixture of oxides of some of the rare metals. This rod does not conduct electricity when cold, but on being heated permits the flow of an electric current. It is therefore necessary to heat up the filament on starting by external means. This is ingeniously done by first passing the current through a fine wire coil surrounding the filament which heats up the filament by radiation to the point at which it becomes a conductor. As soon as the current passes through the filament, the fine wire circuit is electro-magnetically cut out of circuit. The filament contains similar materials to those used in making gas mantles and glows intensely when hot. The light is rich in violet rays, and to a large extent resembles daylight. The efficiency is about 2 watts per candle-power. It takes from a quarter to three-quarters of a minute after switching on the current to light the lamp, the time depending to a large extent on the size of the containing globe, and this is often an inconvenience. Owing to the small size of the filament it is advisable to use an opalescent globe. A complete lamp costs 6s. or 7s., and the cost of renewals with three thousand hours' burning comes out at about 15s. per annum per lamp.

D. **The Open Type Arc Lamp.**—This is perhaps the best known type of electric lamp. In its ordinary form, the light is obtained from the electric discharge between two carbon points maintained a certain distance apart, after the

arc has once been started by direct contact. Many electro-magnetic and mechanical means have been devised to effect these results, and the forms now generally adopted are for the most part simple and effective, which is far more than could be claimed for earlier designs. The length of the arc is usually about one-eighth of an inch, but it varies with the current, the size and quality of the carbons, and the conditions of use.

In the open type of lamp the carbons are usually placed one over the other, and when arranged for direct current the positive carbon, which is the largest, is placed at the top so that the greater portion of the light may be reflected downwards. Open type lamps require from 50 to 60 volts for satisfactory burning on direct currents, and from 35 to 40 volts on alternating currents, and may be arranged in series groups on higher voltage circuits. The carbons need renewing after about twelve hours' burning, but in some recent patterns several carbons are placed side by side so that the lamp burns without attention for far longer periods. A ten ampere direct current lamp gives about 800 effective candle-power so that its efficiency is about ·75 watt per candle-power.

E. **The Enclosed Arc Lamp.**—In this lamp an inner fairly close fitting globe is provided so that the free entry of air is excluded. The arc soon burns up the oxygen present in the small globe, with the result that the pressure required to maintain the arc rises to about 80 volts, the arc lengthens, and the carbon burns away at a slower rate. The efficiency of the lamp falls to about 1·5 watts per effective candle-power, but the convenience of the smaller size and the less frequent carbon renewals have made it very popular. It can be arranged for direct or alternating currents for burning singly on 100 volt or two in series on 200 volt circuits.

F. **The "Flame" Arc Lamp.**—In "flame" lamps both carbons are placed above the arc, usually inclined towards

each other so that they meet at the points. A porcelain cup called the economiser is placed over the points partly to protect the arc from draughts, and partly to reflect the light downwards. The carbons are impregnated with chemical salts so that the light may be tinged with several distinctive colours. Usually the salts used contain sodium so that the light is deep yellow. The arc produced under these conditions is very powerful, and the effect on the ground is far superior to any other form of arc lamp. Photometrical tests show that less than a third of a watt is required per effective candle-power, which makes it fully twice as efficient as an ordinary open type arc lamp. These lamps should not be used in confined rooms on account of the fumes given off by the carbons, but for general illuminating work they are very valuable.

G. **The "Magnetite" Arc Lamp.**—This lamp is favoured for many purposes in the United States, though it is not generally used in this country. In place of carbon the positive electrode is composed of a mixture of magnetic iron oxide, titanium oxide, and chromium oxide, the negative electrode being copper. A usual size of lamp takes 4 amperes at 80 volts pressure direct current, and the lighting effect is said to be equal to that given by an open type arc lamp taking 10 amperes at 50 volts, or about 50 per cent. more energy.

H. **The Mercury Vapour Lamp.**—This can only be used on direct current circuits. A 350 candle-power size lamp consists of a glass tube about 22 in. long exhausted of air and containing a little mercury. On starting the lamp the tube is tilted a little so that the mercury runs from one end to the other and makes contact between the two electrodes. The current immediately fills the tube with mercury vapour, and on the mercury returning to its original position, the current passes through the vapour filling the tube with an intense white glow. This light is exceptionally poor in red waves and rich in violet and

actinic or chemically active waves. The effect of this light is to make red objects assume a purple hue tending towards black, and though blue, green, or violet objects appear more natural, they are still distorted to some extent. The light cannot, therefore, be used for colour matching, and in general its effect on complexions is objectionable, the more healthy looking the complexion, the more ghastly the general effect.

The light is, however, very restful to the eye, and those who have used it long enough to accustom themselves to it are generally in favour of it. In some types of lamp, the absence of red rays are compensated for, and corrected by, combining two or three carbon filament lamps under the same shade. These are very rich in red rays, and so without giving up the whole of the gain in efficiency of the vapour lamp its objectionable features may be overcome.

This lamp is made in two forms, the "Bastian" pattern, the rights of which have recently been acquired by the Brush Electrical Engineering Co. Ltd., and the "Cooper Hewitt" pattern, which is supplied by the British Westinghouse Electric and Manufacturing Co. Ltd. The latter lamp is made in two sizes, of 350 and 700 candle-power respectively. The smaller size burns singly on a 60 to 80 volt circuit, or two in series on a 100 to 150 volt one, and the larger size singly on a 100 to 150 volt, and two in series on a 200 to 250 volt circuit. It is difficult to determine the candle-power of a light of this character, but one 350 candle-power lamp requiring 3·5 amperes at 60 to 80 volts, or, say, 250 watts, will satisfactorily illuminate, when placed about 12 ft. high, about 400 sq. ft. of floor surface.

I. **The "Moore" Lamp.**—This is an alternate current lamp which is not yet in commercial use in this country, though a sample lamp was for some time used in the Savoy Hotel courtyard, Strand, London. It makes use of the well-known discharge of high tension electric currents through rarefied gases. The lamp has been developed in

the United States by Mr D. Macfarlane Moore, and has in it the promise of extended usefulness. A glass tube about $1\frac{3}{4}$ in. diameter is taken in lengths of about 6 or 8 ft. and placed over the place to be lit, the glass tubes being bent and jointed together as required. The tubes are suspended a short distance from the ceiling and walls. The total length of tube thus used for a single lamp should not exceed 220 ft. The closed ends are fitted with carbon electrodes, carried on platinum wires secured to the glass ends, and connected to the high tension terminals of a transformer, the low tension windings of which are connected to any suitable alternating current supply mains. This transformer is wound to give the required pressure, which, with a long tube, may be 10,000 or 12,000 volts. Great care must therefore be taken to protect the ends of the tube and connections. The tube is first filled with nitrogen gas by passing air through it which has passed over pieces of phosphorus so as to extract the oxygen. It is then exhausted to the required degree, and current is switched on, when an electric discharge takes place through the tube, which becomes filled with luminous particles emitting a light which is remarkably like daylight in its illuminating effect. While restful to the eye the light has about five times the illuminating power of the carbon filament lamp.

A number of measurements of the light given off by the tube in the Savoy courtyard were made by Prof. Fleming, who found that to obtain equal illuminating effect at ground level it would require at least one hundred 16 candle-power lamps placed at the same height. The tube lamp required 3 kilowatts to cover all losses, the 16 candle-power lamps would need about 7 kilowatts; this roughly expresses their relative efficiencies. One of the special features of the Moore lamp is the ingenious valve which, as required, admits small quantities of nitrogen to replace that used up in the tube; this has gone far to make it a practical success.

In the United States the lamp is used with great success in drapery stores, silk dyeing works, for picture gallery illumination, and other purposes for which a pure white light is specially necessary.

General Remarks. — Having thus summarised the different sources of light at our disposal, it is possible to indicate a few ways in which they have been utilised for industrial purposes.

It should be remembered that many supply authorities are willing to allow their power customers to use electric energy purchased at power rates for lighting purposes, so long as the amount thus used does not exceed 20 per cent. of the total supply purchased for light and power. This is often a very valuable concession, as it permits of the whole of the lighting to be done with cheap electric energy. Even in cases where the energy used for power purposes is not four times that required for lighting, it will often pay a consumer to divide up his lighting load and place part of it on the power mains, paying for this portion at the cheap power rates. There are some supply authorities, however, who will not allow this, and insist on all units used for lighting being paid for at the higher lighting rates.

In commercial offices it is usually found sufficient to use adjustable pendants placed in rows over the various desks. To get the best effects the light should shine as far as possible over the left shoulder upon the papers or books, the lamps being kept out of the direct line of vision. Opal reflectors are almost universally employed, and now that metallic filament lamps, with their higher candle-power, are coming into use, it is a good plan to frost the lower part of the lamp, and use more of the reflected light from the under surface of the shade. Table lamps, shaded so that only the surface of the table is illuminated, are very convenient, and quite easy to arrange. In a few large offices in the United States the mercury vapour lamp has been used with marked success.

In drawing offices, where a really good light is absolutely necessary, the inverted arc has met with a great deal of favour. In this form of lamp, the arc is formed over a large reflector which directs the light to the ceiling, from which and the walls it is diffused about the room without the workers seeing the source of light at all. This method of lighting is very pleasing but it is uneconomical. From experiments made in the United States, it has been found that the light sacrificed to secure the same intensity as with direct lighting varies from 60 to 80 per cent. of the total.

Recently a number of drawing offices have been fitted with mercury vapour lamps. The result has been a more effective working light at about the same expenditure of electric energy as with the inverted arc lamp. The colour distorting effects of the light are soon forgotten in its more restful nature and the smaller amount of eye fatigue accompanying close application to fine line work.

In textile factories the use of electric incandescent lamps is very general, the current usually being generated from a dynamo driven from the main shafting. In spinning and weaving rooms the lamps should be placed in rows between the machines not higher than 4 ft. or 4 ft. 6 in. from the ground, as the light is required on the parts of the machine opposite the operator. In other rooms the cheaper arc lamp may be employed, the flame type being preferable on account of the softer and more intense light.

Several mills have lately tried using inverted arc lamps and diffused lighting with satisfactory results. The colour of the light, if white light carbons are used in the lamps, is good, and colour matching can be carried on quite easily. The lamps are sometimes placed on standards erected on the floor and at other times hung from the ceiling. To ensure good results, the rooms must be high enough to allow the lamp to be placed out of the line of view and yet a sufficient distance from the ceiling for the rays to be dispersed enough to give even illumination.

In engineering shops a usual plan is to place several arc lamps above the crane for general illumination, and use portable hand lamps on the different tools. This seems rather wasteful, but in practice is found to be satisfactory. It is necessary that the general illumination should be good, while the worker needs at his tool an adjustable light which can best be obtained from an independent lamp.

The same general rules apply to other workshops. Where there are flat ceilings, the rooms being fairly lofty, the inverted arc gives very good results. Open arcs are, as a rule, too brilliant to be used for any but large shops where the lamps can be placed in the roof space. The mercury vapour lamp is good for damp atmospheres such as breweries, mineral water manufactories, parts of textile mills, if direct currents are available, on account of the penetrating nature of the light, while photographers place special value on its actinic properties. The Moore lamp, when simplified, will probably find wide application, while the Nernst, the carbon filament, and metallic filament lamp each have their place in the economical lighting of industrial premises.

The cost at which electrical energy can be obtained is also an important factor in determining the type of lamp to be employed, and the method in which it should be used. There is little doubt that in the near future the tendency will be to make greater use of reflected light, despite its great inefficiency. In the United States many lighting fittings are sold consisting of a suspended inverted reflector, in the centre of which the lamp is placed. For ordinary rooms this is effective, and the same principle has been adopted in recent successful work in this country. Quite recently fittings have been introduced consisting of an upper reflector of large diameter, and a lower one suitably shaped, in the focus of which the lamp is placed. It is thus out of the direct line of sight, and though a considerable portion of the light may be lost in the double reflection, the general effect is good—

cheap energy and efficient lamps of the metallic filament type, greater latitude in the choice of the system of lighting to be used. Electric radiators may often be used in private offices or small rooms, and with electric energy obtainable at power rates, they have much to recommend them on account of their cheerful appearance and great convenience.

The number of lamps required for effective lighting varies so much with the height and general character of the rooms, that it is not possible to lay down any very exact rules. Each case should be studied on its merits and treated accordingly.

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